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SOCIETY OF ENGINEERS.

ESTABLISHED MAY, 1854.

TRANSACTIONS FOR 1881.

PLACE OF MEETING AND OFFICES:

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PREMIUMS FOR 1881.

At a meeting of the Society, held on February 6, 1882, a Premium of Books was awarded to:

JOHN STANDFIELD, for his Paper on "Floating Docks."

And to:

ARTHUR T. WALMISLEY, for his Paper on "Iron Roofs."

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SOCIETY OF ENGINEERS.

ESTABLISHED MAY, 1854.

COUNCIL AND OFFICERS FOR 1881.

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PLACE OF MEETING AND OFFICES:

THE SOCIETY'S HALL, 6, WESTMINSTER CHAMBERS,
VICTORIA STREET, S.W.

1882.

TRANSACTIONS, &c.

February 7th, 1881.

INAUGURAL ADDRESS.

BY CHARLES HORSLEY, A.M.I.C.E., F.G.S., PRESIDENT.

GENTLEMEN,

On taking the Chair this evening, as the President of the Society of Engineers, my first duty is to thank you, and all my fellow Members, most heartily for your kindness in electing me to this position of honour. I need hardly say how pleasureable this duty is, nor how highly I esteem the honour you have done me in placing me here. When I joined our Society, twenty-one years ago, I little thought that I should ever occupy the position I now do amongst you. My hope in joining was, that I might be able to prove of some little use to the Society, if opportunity offered; for I always felt that it was one which deserved well of all its Members. My professional engagements and the exigencies of a busy, practical life for years gave me neither time nor opportunity for helping the Society as I could have wished. I still hoped, however, that the day might come when I should be of service to it. In course of time that opportunity arrived. A few years since you did me the honour to elect me on the Council of the Society, in which position I was able to take part with my esteemed colleagues in the work of conducting its affairs. After a while you did me the further honour to elect me one of your Vice-Presidents. This awakened in me the hope that at no distant day I might possibly reach to my present high position. That hope, by your kindness, has now been realised, and I can only once more heartily, and most sincerely, thank you for thus honouring me. Although when I reflect upon the high qualifications of those who have preceded me in this Chair I fear I shall be found wanting in some perhaps important respects, yet I can conscientiously say that I yield to none in the hearty and earnest desire to do my duty and to strive to the utmost to promote the interests of the Society. With this intention, and this object

sincerely at heart, I throw myself with confidence on your indulgence for any shortcomings that may be found in me. I therefore ask your support, as well as that of my colleagues on the Council during my year of office; and I know I do not ask in vain. This granted, I trust to be able to render such an account of my stewardship as will not deserve your censure, even if it should not call forth your approval. But whatever may be the result, I enter upon my office with an honest determination to carry out its duties to the utmost of my ability.

Having discharged—somewhat inadequately I fear—my first duty of thanking you for placing me at the head of your affairs, I will enter upon my second, which, according to a time-honoured custom, consists in placing before you a few facts relating to our Society, and to review briefly its work during the past year. Following upon this, I purpose to offer a few remarks upon the manufacture and practical application of iron, after which I intend to direct your attention for a while to the most prominent practical developments of science during the past year.

First, then, our own affairs. And here I may congratulate you upon our satisfactory financial position, as evidenced by the balance sheet which you have just heard read. Although we have not a large funded property at our disposal, we have a decent balance at our bankers, a good paying constituency on our books, and an excellent treasurer to look after our finances. We have received an accession of thirty-eight Members during the past year, and we have others now on their way to election, and although, as usual, some have left the Society during the year, their number is far out-balanced by the additions we have made, and our muster roll stands at over 400 Members. Whilst on this subject I would refer, in passing, to a circular which was issued by my worthy predecessor, Mr. Joseph Bernays, on behalf of the Council, inviting attention to the important question of increasing the number of our Members. In this circular attention was first called to the circumstance that the depression which had existed in the engineering profession, and business generally, during the past few years, had naturally had a retarding influence upon the applications for enrolment on our Society's register. That depression has been succeeded by renewed activity, which affords an excellent opportunity for Members to propose to their friends to join our ranks, and thus to bring up our numbers again to their full complement, in order not only to maintain but to advance the prosperity and usefulness of our Society. The late President therefore invited the hearty co-operation and assistance of the Members in the

way of inducing one or more of their friends to join the Society as Members or Associates. As it is of the first importance that the *status* of the Society should be maintained and its interests advanced, I would most earnestly repeat the late President's invitation, and beg of each one present to-night, as well as those absent who may read this address, to do his best to bring in at least one Member or Associate during the year upon which we have now entered. By so doing the Society will be materially strengthened, and its sphere of usefulness widened.

Turning, in the next place, to the papers we have had read before us, you will remember that the first was by Mr. G. M. Ward, upon the "Utilisation of Coal Slack in the Manufacture of Coke for Smelting." The author in the first place pointed out how little attention was formerly paid to the purification of the coal, either before or during the coking process. The prevailing idea was simply to agglomerate the particles of slack, or to put into a marketable form refuse which would otherwise have lain waste. He then referred to the ingenuity which of late years had been brought to bear upon the subject, and which had resulted in the construction at coke works generally of expensive plant and machinery for the separation of the shale, pyrites, and other solid impurities from the slack, prior to its being coked, and to the erection of ovens upon scientific principles for the perfect and economical expulsion of the volatile matter. He then gave some valuable information respecting the process of coking generally, afterwards describing the various kinds of coal-washing, crushing, and screening machines, and coking ovens. For this useful and practical paper the Council awarded Mr. Ward a premium.

The next paper was by Mr. H. W. Pendred on "Distilling and Hoisting Machinery in Sea-going Vessels." In this paper the author described various appliances for distilling sea water. These, as a rule, resemble those used for other purposes, consisting of a worm and a tank, or else they are ordinary multitubular surface condensers, the steam passing through the tubes, and the condensing water circulating through a tank containing them. In some cases the hoisting machinery is combined with the distilling apparatus, as described by the author. In conclusion, he referred to the necessity which exists for a small portable apparatus for distilling water, and heated by some cheap mineral oil. This he thought might often be the means of saving life at sea if placed in the ship's lifeboat.

We then had a valuable paper from Mr. Arthur Rigg, a Member of Council and now one of our Vice-Presidents, on "Sensitiveness and Isochronism in Governors," in which the

author described the variations inherent in the power, or extraneous in the resistance to movements, of an engine, and their effect upon governors. He then referred to the limits imposed upon sensitiveness and isochronism. An illustration of the relay system was given, where the governor moves a valve admitting hydraulic pressure under a plunger to raise or lower the sluice of a turbine, and so regulate its rate of motion. He finally showed that governor and engine should correspond in their relations so as to work harmoniously together, and that perfect regularity was unattainable, and could only be approached by providing sufficient inertia in the moving parts to diminish the effect of irregularities in power or resistance until the governor could operate. He stated that a high rate of revolution attained that condition with the greatest economy and success, and that although the governor might advantageously approach isochronism, its sensitiveness must not be excessive.

Our vacation then intervened, during which several visits were made, to which I shall presently refer more particularly. On resuming our sessional work, the first paper read was by Mr. W. Worby Beaumont, on "Modern Steel as a Structural Material." In his opening remarks the author avowed that his object was not to bring forward any new experiments upon the properties of steel as employed in constructive work, but to promote discussion on a few points which might occur to the engineer to whom it might seem desirable to consider the relative advantage of mild steels and iron in mechanical or constructive work. He then pointed out that the substitution of steel for iron in various structural work had occupied attention for several years past, but that the progress made had not been great in comparison with the expectations formed when steel made by the Bessemer process became cheap enough to make its cost, strength for strength, comparable with that of iron. There were, however, difficulties which attended the manipulation and connection of steel in structures largely composed of plates, which checked its application. Many failures had attended attempts to use it, chiefly resulting from the apparently anomalous behaviour of the metal under what were considered to be similar conditions, but more perhaps owing to the special treatment which it required and received, as compared with iron. He then pointed out that very mild steels were too low in elastic strength, and that the range of ductile extension was unnecessarily great, and he touched on the importance of elastic limit in estimating the structural value of a material, pointing out in conclusion the necessity for a series of experiments on a uniform basis and unit measures on modern

structural materials. For this paper also the Council awarded the author a premium.

Following Mr. Beaumont's paper, we had an interesting communication from Mr. C. J. Alford, entitled "Engineering Notes on Cyprus," in which the author dealt with the water supply of the island, its geology, mineralogy, natural productions, and general capabilities, from an engineering point of view and based upon personal experience. The great requirement in Cyprus, he said, was water, and he recommended irrigation; which it appears had at one time been extensively practised. He described the various towns, including Larnaca, where he advocated the construction of a wet dock. Famagosta, he said, was the best place for a naval station, and it offered no difficulty in the way of constructing railways to all parts of the island. The principal mineral products were iron, lead, copper, lignite, asbestos and salt. He then referred to the defective means of communication, and advanced some propositions for improving them, observing, however, that, as regards labour, the natives of Cyprus were almost useless to the engineer, as physical weakness, combined with laziness, placed them outside the category of useful workmen or labourers. He concluded by observing that there could not be a doubt that with the necessary engineering improvements, carried out with English energy and English money, and with a wise and firm policy to govern the very mixed population of the island, Cyprus would in time become an ornament to the British Crown.

The final paper for the year was by Mr. F. W. Grierson, on the "National Value of Cheap Patents." The author first pointed out that invention was the foundation of our prosperity, and that we could look solely to invention for material advance. He showed that the United States are distancing us as an industrial nation, because their government affords greater facilities than ours does for the practical development of the inventive faculty. He pointed out that while patents conferred on the inventor a small advantage, they conferred a much greater advantage on the country as a whole. He then instituted a comparison between the stamp duties on patents in the United States and Great Britain, which, on his showing, was greatly unfavourable to the latter, and he held that the American view of the beneficial action of patents was the correct one. Although this paper was faultless in construction and style, it had yet one grave defect as far as its arguments were concerned, that defect being that it took a one-sided view of the case, as was pointed out by one or two speakers in the discussion which followed. Time does not now permit me to dilate upon this question, which is a very wide one; I therefore

simply state an objection to Mr. Grierson's theories generally, and in which I believe I am supported by many of those now present.

During the vacation, four visits of a very interesting nature were made to various engineering establishments. The first of these was to the South Metropolitan Gas Works in the Old Kent Road, the Crystal Palace District Gas Company's Works at Lower Sydenham being also visited on the same day. At the South Metropolitan Works we were cordially received by the engineer to the company, Mr. George Livesey, who, with his brother and Mr. Somerville, showed us over their extensive establishment. The most striking feature there was the new gasholder which was in course of construction, and which, when complete, will be the largest in the world. This holder is 214 feet in diameter, in three lifts of 54 feet each, and will contain 5,680,000 cubic feet of gas. The wall of the tank is of concrete, and the cone is covered with 1 foot thick of concrete. The holder is on the non-trussed principle, but having a strong steel crown curb, composed of 6-inch by 1-inch angle steel, rolled to an angle of 105 degrees. I believe this is the first time steel has been used in gasholder construction. It was designed by Mr. Livesey, and involves a new and important structural feature, which is that the holder is surrounded by a perfect network of bracing, which affords great stability under wind pressure.

From the South Metropolitan Works we proceeded to those of the Crystal Palace Company, where we were welcomed by Mr. Charles Gandon, who is one of our Council Members. This company was established in 1854, for supplying the Crystal Palace and the district with gas. The increase of population has led to great improvement in the company's revenue, which has been increased from 10,000*l*. in 1855 to nearly ten times that amount, as at the present time. The plant and apparatus are equal to a daily production of four million cubic feet of gas, the present daily consumption being about two and a half millions, which is stored in six gasholders, varying in size up to 150 feet in diameter.

The next visit was to the railway-signal works of Messrs. Saxby and Farmer, at Kilburn, where we were cordially received by Mr. Farmer, who is an old Member of our Society. The works, which adjoin the London and North-Western Railway, are about three acres in extent, and give employment to about 1000 hands. We there saw the manufacture of railway signals, points and crossings being carried on upon a very extensive scale. The model-room was specially interesting, for there we saw the various manufactures of the firm illustrated by working

models, as well as by full-sized apparatus. The most interesting object was probably the mechanical union of the block and interlocking systems, which was invented by Mr. C. Hodgson, the manager of the works, and was fully explained by him; its working being illustrated by a full-sized apparatus. By means of this combination, a train is hedged about in every possible way with measures of safety, and in a manner which leaves nothing to the care or judgment of the signalman. The interlocking apparatus for points and signals as originally invented by Mr. Saxby in 1856 was explained by Mr. Farmer. As an instance of the progress made in railway development, I may mention that this was a frame of four levers, whilst at the London Bridge Terminus of the London, Brighton and South Coast Railway, may now be seen an extraordinary collection of points and signals, 280 levers being placed in one cabin, and interlocked on the new principle of the preliminary action of the locking gear, that is, the locking actually takes place directly the lever is grasped, and before it can be pulled over, so that with a minimum amount of care no accident should occur.

Our third visit was to the locomotive and carriage works of the South-Western Railway Company at Nine Elms, where we were heartily welcomed by Mr. William Adams, the locomotive superintendent of the company, and a Past President of our Society. We there visited the various departments, and throughout the works we observed evidences of Mr. Adams' desire to substitute, as far as possible, mechanical for manual labour; and of his efforts in these directions there were many instances. The stationary boilers for supplying steam to the engines for driving the machinery had been brought together into one group, and, by a pneumatic arrangement, the sawdust from the sawmill is conducted to them, and is used for fuel. The works cover many acres of land, and give employment to over 1500 people. On each of the preceding occasions we enjoyed the hospitality of our kind friends, who received us most cordially and entertained us most sumptuously.

The last, but by no means the least interesting, visit of the vacation was made to the extension works of the Royal Dockyard at Chatham, where we were received by Mr. Edwin A. Bernays, the superintendent civil engineer, and Mr. W. T. Newton, the executive officer in charge of the works. The works as a whole—finished and under construction—consist of three basins, which have been made in the course of a navigable creek which formerly divided St. Mary's Island from the mainland. These basins communicate with each other, and are supplemented by four graving docks. Two of the basins are finished, and in use, whilst the third is in course of construction. The

first, or repairing basin, has a mean length of 1270 feet, a width of 700 feet, and an area of about 21 acres. Opening out of this basin are the four graving docks, which are all of the uniform length of 469 feet 6 inches. Two of them are sufficiently wide to take any but the latest of our ironclads, whilst the other two will accommodate the *Inflexible.* The factory basin has a mean length of 1245 feet and a width of 700 feet, with an area of 20 acres. The third, or fitting-out basin, which is in course of construction, is 700 feet long, but of irregular shape, and will have an area of about 27 acres. Concrete has been extensively used throughout the whole of these works, and Mr. Bernays has availed himself of convict labour with very satisfactory results. After having inspected the engineering works, we were received by Mr. Penny, the assistant master-shipwright at Chatham, and were by him conducted over several of our ironclads. These recent examples of naval construction included the *Nelson,* of 6000 indicated horse-power, the *Agamemnon,* of similar power, the *Orion,* of 3900 indicated horse-power, the *Superb,* of 7340 indicated horse-power, and, finally, that strange-looking craft the *Polyphemus,* torpedo ram, which is in course of construction. This vessel somewhat resembles the celebrated cigar ship of Mr. Winans. Her engines are of 5500 indicated horse-power. She is steel built, and her outer plating consists of Whitworth fluid compressed steel plates, or scales, measuring 10 inches square, and fixed in place by 1½-inch screws. The *Polyphemus* will be fitted for the discharge of five torpedoes under water, one from her bows and four from her sides.

I have now briefly sketched the work done during the past year, and it will be seen that both our papers and our visits were of an interesting and varied character. In leaving this subject, I would ask you to show your interest in the Society by contributing papers. I am aware that it is not always an easy matter to prepare papers, but I would earnestly recommend the matter to your attention, as good papers are the mainstay of our Society, and are always most acceptable. With regard to our visits, I can only express a hope that the Members—especially the younger ones—will always endeavour to avail themselves of this means of acquiring practical information, for these visits form a most valuable feature in our annual programme, and can only be neglected at the expense of useful professional knowledge.

Having now referred to the leading points in the working of our Society, I will next turn to matters of wider and more general interest. As one whose professional work bears very largely on the production as well as the use of iron, a few words on that important item of manufacture may not be out of

place. Competition in this and foreign countries, through the opening out by new railways of fresh iron and coal measures, and in consequence of every one endeavouring to do more than his neighbour, and to reduce the cost of smelting iron to the lowest amount, has, I fear in many instances, not contributed to the improvement in the quality of iron. The lives of blast furnaces are now of very short duration, compared with what they were in the early part of the present century. I can give two instances of the length of time furnaces lasted without being blown out, which furnaces were at the Alfreton Iron Works, Derbyshire. One blown in during the year 1802 was in blast until 1873, while another blown in during 1811 was not blown out until 1866. This latter furnace was visited by the Members of the British Association during their meeting at Nottingham. After the furnace was blown out, an examination showed that there had been formed a partial lining of plumbago, which protected the firebrick lining: this I think you will admit was a very remarkable incident in blast-furnace practice. I do not find charcoal had been used in smelting during the earlier period of the life of these furnaces. Coke alone was used up to 1829, when equal parts of coal and coke were substituted. The introduction of the hot blast was the cause of all coal being used; at that time the furnace or Tupton coal, mixed with a lower hard coal, was the fuel used. The ironstone used was the argillaceous of the coal series, containing from 25 to 37 per cent. of metallic iron; the iron in the raw stone exists as a carbonate, and requires calcining at a cherry-red heat to convert the carbonate into a peroxide of iron for smelting. Iron made from this ore is very strong indeed. The bands of ironstone, technically called "rakes," are some of them found with the coal seams. The blue rake lies above the lower hard coal. The kernel rake lies above the yard coal, nine different rakes have been worked at the Alfreton Iron Works, and it was found that the greater the variety used, the better and stronger was the iron produced. I find Durham coke the best for smelting purposes. The demand for iron being greater, and the oolitic formation being used, iron-making took a new form. Blast furnaces were constructed to produce very large quantities of pig iron, and works were erected for the purpose of using the oolitic ores alone. In consequence of not having any of the old strong argillaceous ores mixed with them, iron sometimes gets into bad repute, and makers of strong iron are sometimes, to their disadvantage, classed with others who do not so mix the iron ores. I find also that the hard coal of Derbyshire gives the iron a better quality than coke as used in the north. Furnaces using coal do not require to be built more than

50 feet high; but those using coke are best at 70 feet or upwards. Low furnaces are undoubtedly the best for the iron ores lying in the Midland counties, and are about 48 feet high, 3 to 3½-inch tuyeres, pressure of blast 4 to 4½ lb., and blast heated to about 750 degrees. A furnace of this description makes a good tenacious iron from a mixture of ores from Lincolnshire, Leicestershire, Northamptonshire, and the argillaceous ore of Derbyshire, and smelted with the best hard coal, clean and free from pyrites. Remelting iron in the cupola should be very carefully performed. The iron should consist of a mixture of three or four kinds of pigs, and the coke should be very clean and free from sulphur; or, however good the pig iron may be, the remelting will ruin the iron, make it tender, and it will not sustain nearly the strain it should do; hence some of the best founders do not sell pig iron. The metal from the blast furnaces requires testing every day, and if the remelting be carefully carried out, and the castings allowed to remain in the sand long enough to prevent them being chilled, there then need be no fear of the iron not standing the required test, which generally is as follows: That a bar of 1 inch square and 38 inches long, and weighing not more than 10 lb., will, when supported at points 36 inches apart, and loaded in the middle, sustain a weight of not less than 7 cwt.

I think it would be well for every one entering our profession to go first for a time into a foundry, and see for himself the varying contraction which goes on in different kinds of iron. Afterwards he should go into the pattern shop. He would afterwards remember to design his work so that the iron should contract as far as possible uniformly, and so that one part should not fracture another during cooling, which is very often the case. I think, too, that engineers are often asked to produce a certain amount of work, the cost not to exceed a certain sum. This causes the thicknesses of metal to be so cut down that it really is a wonder there are not more accidents than there are.

I may observe, in passing, that the cost of pig iron has been greatly reduced by the gases being taken from the furnaces for heating the air in the hot-blast stoves, and also for the blowing-engine steam-boilers, and for other purposes connected with iron manufacture. This saving in coal in pig-iron making, also in the foundry, and the enormous saving of fuel in steel-making, is to a great extent the cause of the increasing surplus of coal throughout the country. Mr. Hunt's figures show that the average quantity of coal consumed has declined since 1871 to the extent of 16 cwt. per ton of pig iron made in the United Kingdom. As the annual make of pig is almost 6,000,000 tons, the total economy is about 4,800,000 tons per annum. Another

saving occurs in the manufacture of steel rails by the Bessemer process, the quantity of coal required to produce a ton of such rails being generally admitted to be 65 per cent. less than that required for iron rails. The annual production of steel rails is about 650,000 tons, so that we have a reduced consumption of fuel of about 1,166,500 tons as compared with iron rails. There are also other departments of iron-making in which the consumption of solid fuel has been greatly reduced of late years by the use of the waste gases from the furnace, as well as by improved methods of working.

An important and beautiful process for preserving iron surfaces from rust has been perfected and brought into commercial and practical working order during the past year. This is a process invented by Mr. George Bower of St. Neots, and in which he obtains by means of air, but in a superior manner as regards appearances, the same result as Professor Barff does by means of water. It will doubtless be known to you all that Professor Barff, some three years ago, succeeded in applying in practice the well-known principle of exposing iron to the action of superheated steam, whereby it acquires a tenaciously adherent coating of magnetic oxide. This process most effectually protects the surface of the metal from becoming rusted, the iron after treatment assuming a dark greyish, glazed appearance. For long past this process has been in practical use for a variety of purposes, with success. Mr. Bower's process consists in exposing the iron to the action of heated air and the gaseous products of combustion, by which he obtains the necessary coating of magnetic oxide with the advantage of an improved appearance in the articles treated. The apparatus by means of which these results are obtained consists, in the first place, of a set of three small gas furnaces for the production of carbonic oxide. These are constructed by the side of a chamber for holding the articles to be treated. Beneath the chamber is a series of pipes, in which, before entering the chamber, the air is heated by means of the waste heat from the furnaces. The process, as conducted in this furnace, consists in alternately oxidising and de-oxidising the iron. The articles are heated by burning the gaseous fuel inside the closed chamber. Heated air, in excess of the quantity necessary for the perfect combustion of the gas, is made to enter along with the fuel, and this, together with one of the products of combustion—carbonic acid gas—produces next the metal magnetic oxide, and on the top of this a film of sesquioxide, which is reduced to magnetic oxide by shutting off the supply of air, and applying for a short time carbonic oxide only. The time required for the treatment of a charge of

about a ton of small articles varies from three to six hours, and on withdrawing them they are found to be covered with a protective coating of magnetic oxide, which renders them proof against atmospheric influences and the action of moisture. This, however, is not all, as I have already pointed out, for the process gives a new and distinct appearance to the articles. On leaving the heating chamber they are of a dull cherry-red heat, but upon cooling they assume a beautiful French-grey tint, which, like the coating, is permanent. For decorative purposes, when the tint suits, this obviates the necessity for painting the iron. Should, however, the colour not be suitable, from an artistic point of view, the iron can of course be painted, and with the certainty that no rust can ever form underneath the paint to throw it off, as in case of ordinary iron.

Turning to the wider range of professional matters, I think I should not pass by without some slight notice the catastrophe with which the year 1879 closed. I refer to the Tay Bridge disaster, which caused the death of so many human beings at the time, and accelerated, if indeed it did not cause subsequently, that of Sir Thomas Bouch. I need not travel over the history of the disaster, that is well known; I may, however, point out the lesson it teaches us as professional men—for it certainly has a lesson for each and all of us. It will be well remembered that the accident was the subject of a long, anxious, and most searching inquiry before Mr. Rothery, the Wreck Commissioner, Colonel Yolland, R.E., Chief Inspector of Railways, and Mr. W. H. Barlow, President of the Institution of Civil Engineers, who were appointed by the Board of Trade to investigate the matter. Two reports were issued, one by Mr. Rothery, and the other by Colonel Yolland and Mr. Barlow. These two reports were more or less in agreement as regarded the causes and attendant circumstances of the disaster, but they differed in one important respect. The joint report of Colonel Yolland and Mr. Barlow stopped short of attributing blame to any one, whilst Mr. Rothery duly apportioned the responsibility of the disaster. He found that the margin of safety for wind-pressure was much too small, and that there was a great lack of supervision on the part of the contractors. He stigmatised the bridge as having been badly designed, badly constructed, and badly maintained, thus bringing in the railway company for their share of blame in the matter. But although Mr. Rothery went thus far into the matter, I take it that there is a still lower depth into which even he did not probe, possibly because it did not fall within the scope of his inquiry. This lower depth I think was sounded and reached by the editor of *Iron*, when, on the 2nd of January last year, just after the

disaster, he wrote as follows:—"There were undoubtedly several agencies at work tending to conduce to such a disaster, and their combination has as undoubtedly effected it. It is impossible not to believe that those who had charge of the designing and constructing of the bridge did their best to ensure its safety. They doubtless took into consideration all the contingencies that were ever likely to affect its strength and stability, and they no doubt prepared their designs accordingly, and in accordance with the best principle of modern engineering construction. But, unfortunately, underlying all this was the implied, if not expressed, injunction to keep down the cost as much as possible, an injunction which many an engineer of the present day has had to wrestle with. It is possible—nay, we fear it is probable—that in making the Tay Bridge an example of cheapness, those in charge were unwittingly led to leave a smaller margin for contingencies than was consistent with prudence."

And later on, namely, on the 9th of July last, the editor of the same paper, in commenting on the reports of the Commissioners, after referring to the opinion expressed in the passage I have just quoted, writes:—"Such was the opinion we expressed then and still continue to hold, seeing no reason to alter it as regards the fundamental cause of the disaster. The Tay Bridge was a boasted model of cheap and rapid construction, and rarely has parsimonious economy resulted in anything but failure. Those connected with the design, construction, maintenance, and working of the Tay Bridge are undoubtedly to blame, but in fairness to them it must not be forgotten that to some extent they are the victims of a vicious system of cheeseparing, which has obtained of late years in many quarters. But whilst this may tend somewhat to mitigate their culpability, it should be remembered that they had the power of declining to design or execute a work of such public importance with so slender a margin of profit as there doubtless was in the Tay Bridge, well knowing that the margin of safety was equally if not more slender. The disaster will not have been wholly unproductive of good if it leads to reform in this respect, and releases the hands of both engineers and contractors from the parsimonious fetters which too frequently restrain them from healthy action. Nor will the personal finding of Mr. Rothery be regretted if it awaken engineers to a sense of their responsibility, and the Board of Trade to the fact that their certificate is, and naturally must be, regarded by the public as a guarantee of safety as regards the construction of public works."

It seems to me that little, if anything, can be added to this.

It states the case clearly and correctly, and I think it behoves us all, in large as well as small matters, to resist the temptation which sometimes crosses our paths to conform to the requirements of those who have the apportioning of ways and means, and to decline to design or construct a work about which we have to exercise the greatest ingenuity to keep the cost within assigned limits. Better far to have a solid reputation for even over-carefulness, than to earn one which is based upon a marvel of cheapness and rapid construction, and which may possibly fall, and bury our reputation in its reproachful ruins.

One of the most prominent features of the past year, scientifically speaking, has been the great advance made in electric lighting; and it may perhaps prove interesting if I not only give a few particulars respecting this advance, but also briefly notice the various systems of electric lighting which have led to it. One of the earliest systems in the field was undoubtedly the Jablochkoff, with which we have all been familiar for the past two years on the Thames Embankment; the second year of its adoption there having been completed on the 13th of last December. This system consists of what is known as a candle, which is composed of two carbon rods united side by side by means of kaolin. The current is generated by Gramme machines, the arrangement usually being to have one producing a continuous current, and connected with it a second and larger machine producing an alternating current and excited by the first one. The notable example of public lighting by this system on the Embankment is too well known to need comment here. Suffice it to state that on the 13th of December, 1878, twenty lights were started on that portion of the Embankment between Westminster and Waterloo Bridges. On the 10th of May, 1879, the lighting was extended eastwards from Waterloo Bridge to that of Blackfriars, twenty lights being added to the twenty already working. A further extension of the system was effected on the 10th of October, 1879, when ten more lights were placed on Waterloo Bridge, bringing the total number of public lights in that locality to fifty. Later on, ten more lights were supplied from the plant and machinery at Charing Cross, which was originally laid down for twenty lights only, the further extension being the lighting of the Victoria Station of the Metropolitan District Railway. The whole of the machines for these sixty lights are driven by one of Messrs. Ransomes, Sims, and Head's semi-fixed engines of 20 nominal horse-power, there being three pairs of Gramme machines. This development of electric lighting means something more than that sixty lights are successfully maintained from an engine of 20 horse-power nominal. It

means that very considerable distances have been bridged over, and that, other things being equal, electricity can be applied for illuminating purposes at distances from the source of power which appeared incredible a couple of years ago. In the case under notice, there is a light-producing centre at Charing Cross, and the last electric lamp at Blackfriars Bridge is one mile from that centre. The extreme lamp at the Victoria Station, however, is 1·65 miles from that centre, the range of frontage thus actually covered being 2·65 miles. With regard to cost, I may observe that the price paid by the Metropolitan Board of Works under their first contract was *6d.* per light per hour, the lamps being kept lighted for six hours every evening. Upon the Board increasing the number of lights to forty, the price was reduced to *5d.* per light per hour; a further reduction to *3d.* being made when the number was increased to fifty, and the contract renewed for six months. The contract for the year ending the 10th of next April, was taken at $2\frac{1}{2}d.$ per light per hour. The Jablochkoff system of electric lighting is now in operation not only in public thoroughfares, notably in Paris, but in a great number of works and private establishments, as well as in those of public resort. In common with two other systems it has been selected by the Corporation of London for the illumination of a portion of the City.

One of the other two systems to which I have just alluded is that of Messrs. Siemens Brothers, which has been in operation for some years past for lighthouse illumination and for other purposes, including interior lighting. An excellent example of its application in this latter respect is to be seen at the British Museum, the reading-room of which was first thus lighted in October 1879. Eleven lights in all were fitted up, four being in the reading-room, four in other parts of the Museum, two in the courtyard, and one at the rear of the building. The four lamps in the reading-room are supplied with continuous currents, each from its own Siemens dynamo-electric machine. The other seven lights are supplied from one Siemens machine, producing an alternating or dividing current, two different systems thus being used. The motive power for driving the machines, which are six in number (the sixth being an excitor for the other five), is afforded by two eight-horse semi-fixed engines, by Messrs. Wallis and Stevens. The most recent, as well as the most extensive, example of outdoor lighting on the Siemens system, is that at the Royal Albert Docks at Silvertown. The entrance dock is 700 feet in length, and opens into a tidal basin having a water area of 12 acres. This basin again opens into the main basin, which is 6500 feet in length, 500 feet in width, and has a water area of 72 acres. Connected

with the main basin are two graving docks, one 410 feet, and the other 500 feet, in length. The whole of this extensive area, which is about $1\frac{3}{4}$ mile in length, is electrically lighted by 26 Siemens lamps. There are four generating stations, in each of which is a 20 horse-power horizontal engine, by Messrs. Marshall Sons and Co., driving seven Siemens dynamo machines, which act as light-producers, and an eighth machine of the same kind, which is used as an excitor. Each lamp is placed on a wrought-iron latticed standard 80 feet high. The stations have been arranged with a view to the further extension of the light space, power being reserved for supplying a total number of 24 lights from each station, or 192 lights in all.

The third system of electric lighting selected for the illumination of a portion of the city is the Brush system, which was introduced into England at the close of 1879 from the United States, where it was then in very extensive use, its adoption having since largely increased. This light is particularly well suited for interior illumination, for which purpose it has come into considerable use since its introduction in our own country. It is the invention of Mr. C. F. Brush, and it consists of a dynamo-electric machine of special construction. The lamps, or regulators, hold the carbon rods in a vertical position, and contain no clockwork or other mechanism; and no regulation or adjustment of any kind is required beyond that of renewing the carbons when consumed. An outdoor example of illumination by means of the Brush light is to be seen at the Liverpool Street Station of the Great Eastern Railway, and it has also been applied at the Houses of Parliament.

There are several other systems of electric lighting which are more or less prominently before the public, but which do not appear to have made such advances as those to which I have already referred. I cannot, however, pass them over without notice, as they each possess merit, and some of them may eventually come well to the front. The first of these is the Rapieff light, which was brought out in June, 1878, and has since been adopted in the composing and printing rooms at the *Times* office, but I am not aware of its adoption elsewhere. The current is supplied from a Gramme machine, and the light produced is a very good one for internal illumination. The Wallace electric lamp was introduced in October, 1878; the light is produced in it along the edges of two carbon plates placed one over the other, edge to edge. The current is generated by a Farmer-Wallace dynamo-magnetic electric machine. Although this system promised well when tried experimentally, I am not aware that it has been adopted in

practice anywhere in this country. The Werdermann electric light, which was introduced in November 1878, differs from most other systems, inasmuch as it is a light of incandescence, the others having the voltaic arc. In the Werdermann system the carbons impinge upon each other, that is, they make contact; whilst in most other cases a definite space is preserved between the carbons—that of the voltaic arc. In the Werdermann lamp a carbon disc and a carbon rod were formerly used, but the carbon disc has since been replaced by one of copper. The current is supplied by a Gramme continuous machine, and the lamp is gradually coming into use for interior illumination, for which purpose it appears to be well adapted. The only other systems remaining for notice are the Wilde, the Jamin, and the Mackenzie lights. The Wilde electric light apparatus consists of an electro-magnetic induction machine, producing alternating currents, and a carbon-holder or lamp of simple construction. It was brought before the public in December 1878, but I have not observed any record of its application, although, being a system which at its introduction promised well, it should, and doubtless has, met with some degree of success. The Jamin light consists of three electric candles, each candle being composed of two parallel carbon rods. The candles are burned, one at a time, point downwards, and the current is produced by a Gramme dynamo-electric machine. The new Royal Panorama in Leicester Square is to be lighted by this system, which is also being applied in a mercantile establishment on Ludgate Hill. Lastly, there is the Mackenzie electric lamp, which is about the latest addition to the list, having been introduced to public notice so recently as October last. The light is produced between the points of two carbon rods placed vertically one over the other, the consumption being followed up by means of an electro-magnetic arrangement. The current is produced by either a Siemens or a Gramme machine. The lamp worked satisfactorily for three weeks at the Exhibition of the Philosophical Society of Glasgow in October last, but I have not yet met with it in practice. As an indication of the progress made in electric lighting, I may mention that two companies, which at the commencement of the year were simply companies for experiment and development, have recently found it necessary to undergo reconstitution as companies for the practical working of the systems they respectively represent. These systems are the Jablochkoff and the Brush.

It will thus be seen that there are nine different systems which have been brought more or less prominently before the public, although there are but three of which it may be said that they

are fairly in the field as illuminating agents. These are the three to which I first directed attention. With regard to cost, there is little or nothing known generally.

There can be little doubt that for certain purposes and under certain conditions electricity is desirable as an illuminating agent. Its cost, delicate, and in some cases complex, arrangements, and comparative uncertainty, however, will long prevent its adoption becoming general, much less universal; but where expense is no object, users can avail themselves of its advantage. I must not leave this subject without referring to the endeavours of Mr. Edison, that American genius, to perfect the electric light. All the patience, toil, perseverance and remarkable intelligence of Mr. Edison have, however, not yet been rewarded with success, the promise of a couple years ago remaining unfulfilled to this day. Nor can I see, after all that has been said about and for him and his electrical productions, that he is one whit more forward in the practical application of the electric light than we are here in England; if, indeed, he is so far advanced. Mr. Edison has done much good work for electric telegraphy and electrical science generally, for which he has earned the gratitude of the world; but Mr. Edison's friends have done him and his credit much harm in the matter of electric lighting, for which they have earned the contempt of every disinterested and thinking person.

The appearance of the electric light in some of the streets and establishments of London about two years ago, was the signal for what at the time was known as the "gas scare." Many foolishly imagined that the reign of gas was at an end, and that it would be superseded within a very short period. Those however who took the trouble to think about the matter, saw that not only would gas still hold its place for general purposes of illumination, but that its use would actually increase. They remembered the predictions which were rife half a century ago upon the advent of railways, to the effect that horses would be rapidly superseded by locomotives, and they reflected upon the present high price and enormous demand for those animals. They remembered, too, how upon the introduction of gas it was said that candles would become a curiosity in a year or two and oil go a-begging, and they called to mind the extensive candle factories which are now to be seen in and about London and the provinces. Inspired by the partisans of Mr. Edison, some of the more garrulous of our daily papers helped to fan the flame; which, however, in course of time, became extinguished, as common sense began to regain its sway. There was, however, some show of reason at the bottom of the panic, for the public had been accustomed to

such a miserable show of dingy yellow gas spots in our thoroughfares that, dazzled by the new light, they could not conceive that gas illumination could be improved except at a prohibitory increase in cost. That the deficiencies of our street illumination are not due to the impossibility of obtaining a better light by the aid of gas except at a prohibitory cost was amply proved in three instances on a large scale during 1879. These three instances were so many practical answers to the doubts raised upon the subject, and they were conclusive answers too. These were, firstly, the special lighting of a portion of the Waterloo Bridge Road in January 1879 by the then Phœnix Gaslight Company; secondly, the special lighting of Waterloo Place and a part of Regent Street by the Gaslight and Coke Company in the following month; and thirdly, the special lighting of a portion of Queen Victoria Street by the same company. In each instance Sugg's London Argand burners were used, the lanterns being also specially designed by Mr. Sugg. The burners ranged from 15 to 200 candles, according to position and other attendant circumstances, the larger burners being placed on refuges and at the intersections of roads. In each case a generous but not an extravagant display of gas-lighting was afforded, and the immediate result of the experiments was to demonstrate most conclusively that in order to obtain a good light the conditions of illumination must be considerably modified and the cost somewhat increased, but not to anything like the prohibitory extent imagined by some. The practical outcome of these experimental displays, by which the gas companies showed what they could do if required, has been the adoption in many parts of London and the suburbs, and in many of our provincial towns, of the methods of illumination then employed by Mr. Sugg, who in each case carried out the views of the gas companies most creditably.

Not only did the advances made by the electric light warm into action the gas companies, but it also aroused gas engineers and those engaged in the manufacture of gas apparatus, so that in a short time there were several systems of improved gas illumination to make choice of. Amongst others, the Bray burner has been adopted in some parts of London and in some parts of the provinces as a special illuminator. The arrangement consists of a cluster of flat-flame burners of large capacity placed in a lantern similar in design to Sugg's. It is claimed for Bray's burners that they yield 20 per cent. more light with the same consumption of gas than those used in ordinary street-lamps. The Phare gas-burner is another flat-flame burner, and consists of a circle of gas jets in combination with an arrangement for supplying the necessary quantity of air, the whole being con-

tained within a special lantern. It is the invention of M. Phare, a French gas engineer, and a number of them are in use in the Rue de 4 Septembre, Paris, where they are reported to be giving satisfactory results. For three months in the beginning of last year one of these lamps was to be seen in front of the Mansion House, London, and I believe there is one on the Old Steyne at Brighton. Of a somewhat similar character to the Phare lamp, but giving inferior results, is the Mallet burner, which also hails from France, but which, as far as I am aware, has not gone beyond experimental trial in this country. The Wigham lantern and burner, the former being of hideous proportions, were in use for a short time towards the close of 1879 on the refuge at the top of the Victoria Embankment, by Westminster Bridge, where four lamps were placed. The burners were similar to those used in lighthouses and also for the signal light on the Clock Tower of the Houses of Parliament. This burner consists of twenty-eight fish-tail jets placed close together in a group and surrounded by a sheet-metal cone, through which the air is conducted to the burners. Over the burners is a tubular flue for drawing the air over the tops of the flames in order to effect a more thorough combustion of the gas than would otherwise occur, the lantern being surmounted by a ventilating cowl. Those who saw the light will doubtless agree with me that there was a great blaze of gas, which, however, did not appear to be so economically used as it might have been. It will thus be seen that there are several systems of improved gas illuminations which offer themselves for choice, the advance of the electric light having caused a corresponding development in the direction of gas-lighting.

The electric light has, however, done much more to increase the consumption of gas in another direction, namely, that of producing motive power. The application of the electric light has largely increased the manufacture of gas engines for driving the machinery for producing the current for interior illumination, and there can be no doubt that a good gas engine, and I advisedly say a *good* one, is a most useful motor for electrical purposes on a small or even a moderate scale of lighting; that is, for interior illumination. Besides this, the advantages possessed by the gas engine over steam, and the perfection to which it has been brought, have rendered it available for numerous other purposes where only small powers are required, and where the use of steam is prohibited. Then again, the use of gas for heating and cooking purposes is also making steady progress, if one may judge from the number of useful arrangements for the purposes which are before the

public, and to which additions are occasionally being made. For heating rooms, conservatories and baths by means of gas, special arrangements are continually being devised, with the view of minimising the consumption of gas in detail, but thereby increasing the demand for it in the aggregate. For cooking purposes, the use of gas appears to be largely on the increase, and with a properly designed apparatus nothing can be more desirable on the score of cleanliness and economy. There is, however, one condition which must steadily be observed in whatever way or for whatever purpose gas is used, and that is, that it must be burned upon scientific principles and not in a hap-hazard or rule of thumb manner, regardless of proper control. The exercise of a controlling power over gas during burning has formed one of the chief studies of gas engineers ever since the first practical introduction of gas-lighting, and it continues to do so, notwithstanding the great advances that have been made in the science of gas-lighting in recent times. The power of control is the key to the efficient and economical use of gas—that is, the production of a good light at a low cost. As an illustration of what I mean, I may mention that with the old Argand and fish-tail burners, the gas issued from the small holes at the point of ignition with a velocity of from 60 to 90 miles an hour. With the best known modern burner, Sugg's London Argand, the gas issues from holes with a velocity of only a little over 1 mile per hour. This forcibly illustrates the necessity for a governing power being exercised. It is a singular but well-known fact that the highest results in illuminating power are attained when the gas issues from the burner with the lowest velocity. To sum up, I consider it to be highly probable that, irrespectively of what I may term its subsidiary uses, coal gas has a future of considerable promise before it as an illuminating agent. The electric light is far from being capable of universal application at present, but the progress made in its development demonstrates its usefulness in many important respects. Its special application will only engender a desire for better illumination in directions where electricity is not yet available for use, and here the improved system of gas-lighting should come in. Notwithstanding all that has been done of late years towards introducing scientific principles in the burning of gas, there is still room for improvement. A careful study and correct appreciation of the laws which govern the scientific use of gas will lead to conclusions which, if acted upon, will conduce no less to the benefit of the consumer than to that of the producer.

Before quitting the subject of gas illumination, I may perhaps refer to coal gas as an illuminator for railway carriages. It is

in use on one of the metropolitan lines of railway, and to a certain extent it answers the purpose, although there is the objection that the reservoirs on the carriages have to be replenished many times during the day. This renders ordinary coal gas unfit for lighting carriages for long journeys. Attempts have been made, and still are being made, to enrich ordinary coal gas and to burn it under pressure in the carriages, and early in the past year such a system was under trial on the Great Northern Railway; but as far as I am aware it has not yet been adopted on that line in practice, although at the time trains were successfully run to the north and back. Another system of carriage-lighting with gas is gradually coming into use, the results being very marked, both as regards economy in cost, steadiness of light, and high illuminating power. This is Pintsch's system, in which the illuminating agent is oil gas, which is produced mainly from shale-oil refuse. The refuse is distilled in retorts, in which it is completely decomposed, the gas being conducted from the retorts to condensers, after which it passes through a washer and two purifiers to a meter, where the quantity produced is registered on its way to a gasholder in which it is temporarily stored. From the holder the gas is forced by a compressing engine into iron store-tanks, where it is stored for use under a pressure of 150 lb. per square inch. For delivering the gas to the carriages, which are fitted with wrought-iron receivers, a number of filling-posts are fixed at intervals on a gas-distributing main laid in the ground in any convenient part of the station or at a siding. To supply the carriage-receivers, a flexible hose is slipped on to the filling-post and connected with the receiver on the carriage, the gas being admitted into and stored in the receiver at a normal pressure of 90 lb. per square inch. The most recent example of the adoption of this system is that in connection with the London and South-Western Railway, the oil-gas works being situate at Clapham Junction. Similar works are to be found at the Mansion House Station, in connection with the District Railway; at Stratford, on the Great Eastern Railway; at Baker Street and Hammersmith, on the Metropolitan Railway; and on the South-Eastern Railway. It is in extensive use on the Continent, and its adoption on the South-Eastern line renders it possible for passengers to run from London to St. Petersburg—saving the Channel passage—in trains lighted on Pintsch's system. As a matter of fact, 19 per cent. of the passenger carriages on the German railways have already been fitted with this light, while in England the carriages running and in course of being fitted upon Pintsch's system amount to considerably over 1000.

Considerable interest has been evinced during the past year in working with high-pressure steam on Perkins' system, a very remarkable voyage having been successfully performed by a little steam yacht—the *Anthracite*—engined on this system. This example of steam-engineering is so interesting that I may perhaps be pardoned if I detain you for a few minutes whilst I describe the vessel and her machinery, as she is the smallest steamer that has ever undertaken a voyage to America on her own unaided resources. I may first observe that the Perkins system consists of a tubulous boiler in which steam is generated at a very high pressure, and a special system of engine in which the steam is used and re-used over and over again. The boilers are charged with fresh distilled water, a small quantity only being required; and this, after being converted into steam and used in the engine, is condensed and re-used. The advantages of this system are, a very small consumption of fuel, immunity from explosion by reason of the subdivision of the boiler into numerous parts, each part having a high resisting power, and durability of the boiler, which is estimated as being equal to that of the engines and ship. The boiler is constructed of horizontal tubes welded up at each end, and connected by small vertical tubes, and is proved to 2000 lb. per square inch. The engine has three cylinders of different diameters, the smallest cylinder being placed over that of medium size, and being worked from the same piston rod. Steam is used at pressure varying from 300 lb. to 500 lb. per square inch; 350 lb. being the ordinary working pressure. The *Anthracite* is 84 feet long, 16 feet beam, and 10 feet deep, her engine and boiler room being 22 feet 6 inches long. Her gross tonnage is 70·26 tons, and her registered tonnage 27·91 tons. Her engine cylinders are of 8 inches, 16 inches, and 23 inches diameter respectively, with a 15-inch stroke. They are of 20 nominal horse-power, and 168 indicated horse-power. The high-pressure and medium cylinders are single acting, the low-pressure cylinder being double acting. Her Atlantic voyage out and home is reported to have been very successful, her engines and machinery on her return showing no signs of being any the worse for wear, after having steamed 10,000 miles with the steam pressure varying from 300 to 400 lb. per square inch, all the time during which it is stated that no repairs whatever were necessary either to her engines or boiler. In the Brooklyn Navy yard, the United States authorities had her under continuous trial for four days and nights, with satisfactory results. After that she steamed to Philadelphia and thence to Falmouth and on to London, doing 3126 knots on 25 tons of coal less than that consumed in the galley fire. The total number of

revolutions made by the engines from the time of starting from England to the end of the voyage was 8,484,245. The *Anthracite* is not only the smallest steamer that has ever steamed across the Atlantic, but is probably the only one of her size in England that could perform such a feat. Prior to leaving England she was tested by Mr. F. J. Bramwell, C.E., in a very thorough manner for economy of fuel and with excellent results.

Turning from steam to air as a source of motive power, it may be interesting to observe what progress has been made during the past year towards a practical solution of the use of compressed air in this connection. The solution has been closely approached by Colonel Beaumont in his compressed air engine, which came prominently before the public about eight months ago. The main difficulty which has perplexed inventors and has retarded the progress of the air engine has been that of providing means whereby the full power contained in the air under compression can be utilised economically and at serviceable pressures. That difficulty appears to have been overcome by Colonel Beaumont in an air-driven locomotive, which was at the time of which I speak running in the Royal Arsenal, Woolwich, where it had been put to the test of practical work. The construction of the engine is based upon the principle of utilising the power stored up in compressed air, no matter how high the pressure may be. This is effected by admitting the air into successive cylinders having different areas, commencing with the smallest, and in making provision whereby, as the pressure falls in the reservoir, the consumption of the air can be increased. In other words, the elasticity and the expansive properties of the air are taken full advantage of in this engine just in the same way as the corresponding properties in the vapour of steam are utilised in the compound steam engine. In each case the gases are expanded from the smaller and high-pressure, into the larger and low-pressure cylinders.

In appearance and construction the air-locomotive greatly differs from those of the ordinary type, as it more or less resembles a large tank carried upon wheels. This, however, was the first and experimental form, which has since been improved upon. In working, the air is first compressed by a stationary compressor into the reservoir of the locomotive, where it is stored under a pressure of 1000 lb. per square inch. After passing successively through the three cylinders the air is noiselessly ejected into the atmosphere. A difficulty always present when highly compressed air is expanded is the cold produced, which condenses the moisture in the atmosphere and

deposits it in hoar frost upon the working parts. Colonel Beaumont meets the difficulty by the application of heat externally to the cylinders, the engine having a small steam generator attached to its framing. The engine is so arranged as to be capable of making a run of 20 miles with one charge of compressed air. Whether this has been done I am not aware, but it is reported that the engine has hauled a gross load of 22 tons for a distance of 11 miles, and a lighter load of 12 tons for over 20 miles, with one charge of air, and this under the observation of the Arsenal authorities. The engine itself weighs 10½ tons. The principle has since been carried out in improved forms of engine for tramway use, and with these some experiments have been carried out during the last autumn. With regard to the practical progress made by the Beaumont engines, I may mention that the engine tried in Woolwich Arsenal with such success is now being tried with a view to its adoption on the Metropolitan Railway, as the system largely overcomes the difficulty of ventilation on underground lines. A second engine of smaller capacity ran for several weeks on the tramway at Leeds, and has recently been running in the Royal Albert Docks. A third engine is being built for working some of the metropolitan tramways. The fixing of the permanent compressors to supply air for a service of 500 miles per day is nearly finished, and when the arrangements have been completed regular running by means of compressed air will be commenced.

Physical science has been enriched during the past year by the perfecting of the photophone by Professor Graham Bell, who with Mr. Sumner Tainter carried out a series of experimental researches which led them to the discovery of the transmission of articulate speech by means of an undulatory beam of light projected from one station to another. Hence the photophone. The reproduction of the voice by light is managed in the following manner:—The speaker's voice is directed through a tube against the back of a looking-glass of extremely thin material, namely, microscopic glass silvered. A beam of light is thrown on the front of the glass, the thin glass vibrating in response to the speaker's voice, assumes alternately convex and concave forms, and thus either diffuses or condenses the light. The beam of light thus varying in intensity according to the sounds acting upon it is received at the other end in a parabolic reflector. What follows is due to the ingenuity and labours of Professor Bell and his colleague in their endeavours to make the most of Mr. Willoughby Smith's discovery that in selenium an electrical disturbance is produced by light. They have perfected an arrangement in connection

with their light-receiver by means of which the sensitiveness of the selenium is wonderfully developed. When the varying beam of light falls on the selenium, an electrical disturbance is produced similar to that which is conveyed by wire in the ordinary telephone, and the vibrations of the speaker's voice are then accurately reproduced in an ordinary telephonic receiver. The way does not at present seem clear for the practical application of this remarkable and beautiful discovery, but the day may not be far distant when its use may be as amply manifest and may become as wide-spread and as important as that of the telephone.

I have now brought before you what I think are the leading scientific features which have distinguished the past year. I could add to these many matters of minor interest and importance the notice of which would fall well within the scope of an address like the present. But as I do not wish to begin my year of office by either taxing your patience or wasting your time, I think it best to leave these unnoticed. The points upon which I have touched I have endeavoured to make interesting, and where possible, instructive, and I can only hope I have succeeded. I thank you, Gentlemen, for the kind and patient hearing you have given me, and trust you will excuse any defects you may discover in the observations which it has afforded me much pleasure to bring before you. I have already said that our Society is in a very satisfactory condition. Let me in conclusion express the hope that when I leave this Chair in favour of my successor, the Society will be not only in as satisfactory a condition as I now find it, but that it will be further improved and developed. I assure you it will be my constant aim to bring about this desirable end.

March 7th, 1881.

CHARLES HORSLEY, President, in the Chair.

GAS-ENGINES.

By Charles Gandon.

The use of coal gas as a motive force is of comparatively recent origin and, considering that its introduction for lighting purposes dates only from the commencement of the present century, it is not a matter for surprise that its utilisation as a substitute for steam should be still quite in its infancy.

It is true that, even before the introduction of coal gas, many proposals were made for obtaining motive power by exploding gaseous mixtures in closed cylinders, but none of these proposals seem to have been brought into practical use, and the danger and expense of producing such explosive mixtures seems to furnish sufficient reasons for none of the proposals having been successful.

In 1794, a patent was taken out in England for producing an inflammable vapour force by exploding the vapours of spirits of tar or turpentine mixed with air in a cylinder, the bottom of the cylinder being heated sufficiently to vapourise the liquids, and the vapour ignited at a touch-hole like a gun. In 1807 a patent was taken out in France for propelling carriages by the explosion of a mixture of hydrogen gas and air. Following upon these, numerous other inventions were patented for similar purposes, but they all seem somewhat obscure as to the nature of the explosive compounds to be used, and the means for obtaining the same; mixtures of oxygen and hydrogen, hydrogen and atmospheric air, carburetted hydrogen, inflammable vapours, gun-cotton, and various other gases or substances being proposed; but, although carburetted hydrogen (which is the principal constituent of coal gas) is mentioned by some, it appears that the idea of utilising coal gas, as made for lighting purposes, was first practically applied for working engines in the "Lenoir" and "Hugon" engines, which seem to have been brought into notice at about the same time. Since these

were introduced, so many improvements have been effected in the construction and mode of working engines with gas, that they now promise to become important additions to the motors of the future.

The "Lenoir" gas-engine was patented in 1860, and seems to have been first introduced into this country at the Exhibition of 1862, where it attracted much attention; but, although it met with some success, its construction was so complicated, and its consumption of gas so excessive, that it did not come into very general use: the sudden and violent explosions of its charges of gas and air caused much damage to the working parts, and its useful effect was much diminished from the same cause. This engine was afterwards improved in many of its details, but the consumption of gas, being about 70 cubic feet per I.H.P. per hour, still remained excessive, and it retained the further objection of requiring a battery for the production of an electric spark for the ignition of the charge. It was similar in appearance to an ordinary horizontal steam-engine, the gas and air were admitted into a slide-valve chamber and passed through a series of small openings in the valve into the cylinder, alternately on each side of the piston; wires from a battery were inserted at each end of the cylinder, by means of which sparks were produced for the ignition of the mixture, the current of electricity being cut off at certain parts of the stroke. The explosions, causing a considerable expansion of the gases, forced the piston alternately to each end of the cylinder, means being also provided for the escape of the products of combustion.

The "Hugon" gas-engine resembled in many respects the one just described, and it possessed the same defects of sudden and violent explosions, and consequent excessive wear and tear, and it also required a battery for the ignition of the charges, and, at least in this country, it does not seem to have met with even so much success as the "Lenoir" engine.

In these first engines, the necessity for the employment of the electric spark for the explosion of the charges was a considerable drawback. The most simple means for effecting this was evidently by the employment of a jet of gas, but the difficulty in its use seems at first to have been the liability, or almost certainty, that the jet would be extinguished by the force of the explosions; this was overcome in more modern engines by the employment of two jets, one of them being permanent and cut off from communication with the charge during its explosion and serving to relight the other jet communicating with the charge after each explosion had taken place.

After the "Lenoir" and the "Hugon" engines, the next gas-

engine to deserve attention was the "Otto and Langen," and, as this dispensed with the use of electricity, it was certainly a step in advance. It consisted of an upright cylinder, into which, on the underside of the piston, a mixture of gas and air was admitted and there fired by a gas jet. The explosion forced the piston suddenly upwards, but this force was not utilised directly for communicating the power, as in the upward stroke the piston-rod was disconnected from the crank-shaft, and, a vacuum being formed on the lower side by the condensation of the products of combustion, the piston was forced downwards by the atmospheric pressure on its upper side, and, in the downward stroke, becoming connected with the crank shaft, it imparted the motive power. Considerable numbers of these engines were put into use, both in England and on the Continent, and they were fairly successful for small sizes where the intermittent use of an engine was required; but the alternately rapid and slow motion of the piston, with its rack and pinion gearing, and the loud noise of its explosions, were objections to its use in many instances, although it effected a considerable economy in the consumption of gas as compared with former engines.

A great improvement in gas-engines has now been made by the discovery that, although small proportions of gas mixed with air will not explode under ordinary atmospheric pressures, yet they will explode, or more correctly ignite, if compressed, and that, under these conditions, the force exerted is not sudden as in an explosion of a charge not compressed, but is gradual and continuous.

The explosion or ignition of coal gas in combination with air varies in effect according to the proportions in which the two are mixed. A mixture of three parts air and one part gas will explode, but with a greater proportion of gas it will simply burn, and between that proportion, up to eight or ten parts of air to one of gas, the mixtures are explosive at ordinary pressures, the proportions being subject to variations according to the composition or quality of the gas; but, as a rule, the larger the admixture of air, the greater will be the total force of the explosion in comparison to the quantity of gas employed; if, therefore, by putting the mixture under pressure, a larger proportion of air can be used, as is found to be the case, in addition to the economy of the gas, greater power is obtained by reason of the more gradual development of the force.

Advantage has been taken of this fact in several of the more recently designed gas-engines, among which the most successful seems to be the "Otto Silent Engine," made in this country by

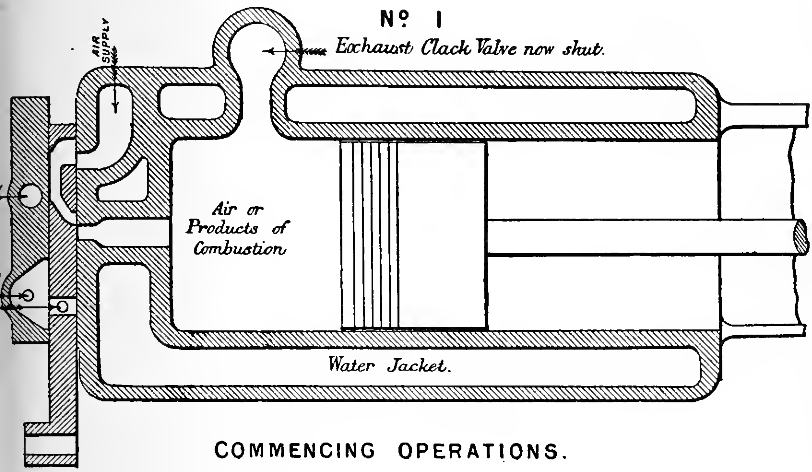
Messrs. Crossley Brothers, of Manchester. This, as now made, is a horizontal engine, the cylinder being open at the front end, and considerably longer than is required for the stroke of the piston, thus leaving a space between the piston and the back of the cylinder in which the charges of mixed gas and air are received and compressed. The slide-valve is of peculiar construction, having port-holes in it corresponding with holes in the back of the cylinder, and with others communicating with the gas and air supplies for the admission of gas and air into the cylinder in proper proportions, and at certain parts of the stroke, and it also communicates with the lighting jets for igniting the charge.

At starting, the space at the back of the piston is filled with air; as the piston moves forward, further quantities of gas and air are drawn in, and, by the return stroke, the whole contents of the cylinder are compressed into the space behind the piston; at this moment the port-hole communicating with the gas jet becomes open to the charge and ignites it, the ignition being gradually communicated to the contents at the back of the piston, the expansion of the gases driving it forward; at this point the exhaust valve is opened and the piston, in returning, expels the products of combustion, and on again moving forward it draws in a fresh charge of gas and air which, in its turn, is exploded as before.

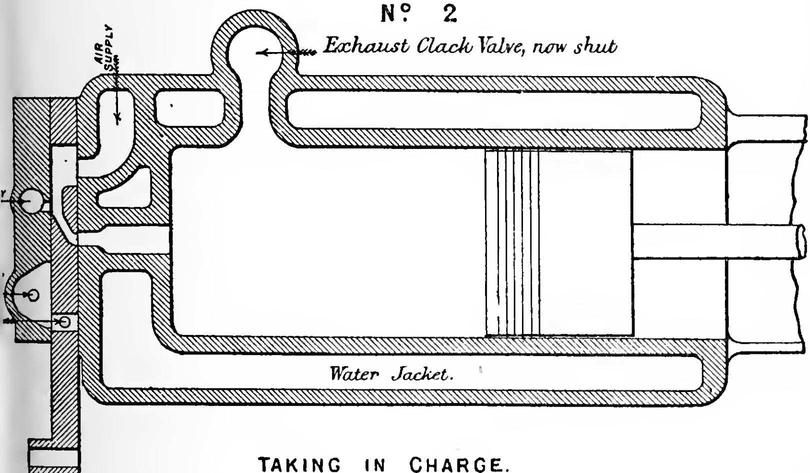
It will be seen from this, that the explosion or ignition of the charge takes place only once in every two revolutions of the crank shaft, the power being meanwhile maintained by the momentum imparted to the fly-wheel; and by an ingenious arrangement of the governor, which controls the opening and closing of the valve for admitting the gas, the explosions may occur less frequently, say at every fourth revolution, if the engine is not doing its full work. By the adjustment of the governor, the engine has to work at a practically uniform speed whatever amount of work it may be performing, and, if this speed has a tendency to increase, from want of resistance to be overcome, the governor, by rising, prevents the admission of gas, and no explosion takes place. The speed is not absolutely uniform, but the action of the governor is so sensitive at the high speed at which these engines are set to run (170 to 180 revolutions per minute) that it becomes practically uniform, and may, of course, be varied within certain limits according to the weight of the governor; but for this to act satisfactorily the speed must necessarily be high.

The diagrams Nos. 1 to 7 on the wall are given to illustrate the conditions of the charge in the cylinder at different portions of the stroke.

In No. 1, the engine is supposed to be ready for starting with the piston at its extreme point within the cylinder, all the port-holes in the slide-valve being cut off from communication with the cylinder and the exhaust-valve just closed.



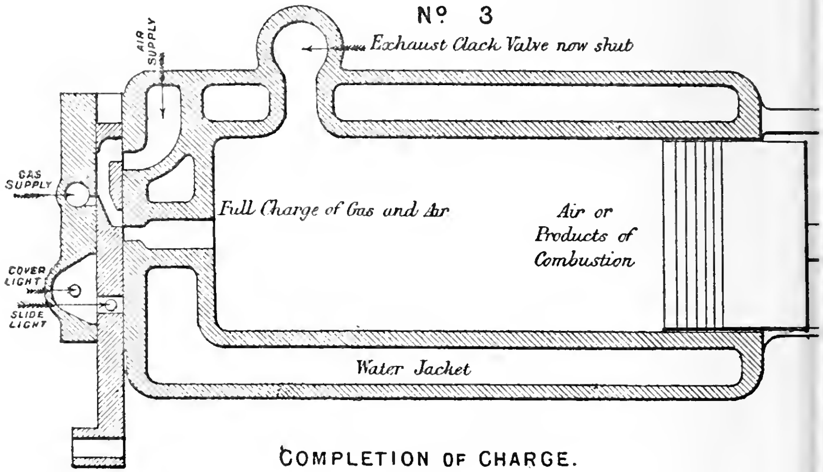
COMMENCING OPERATIONS.



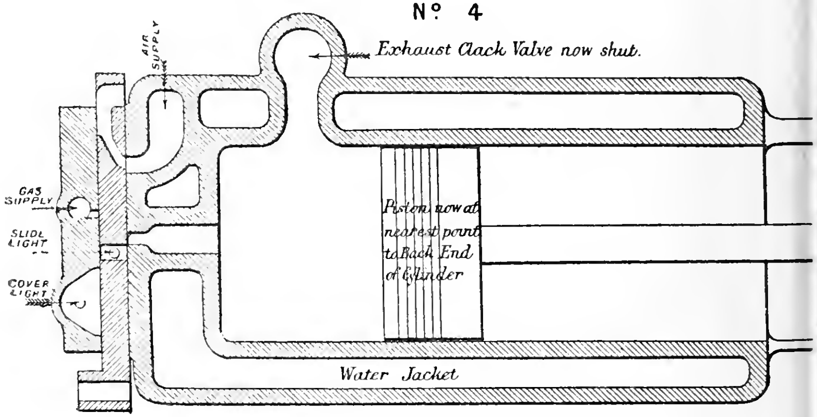
TAKING IN CHARGE.

No. 2 shows the piston advancing forward, with the port-holes communicating with the gas and air supplies open to the cylinder, the exhaust being still closed.

No. 3 shows the piston in its most forward position, the full charge being now drawn into the cylinder and the supply ports cut off from communication with it.



COMPLETION OF CHARGE.

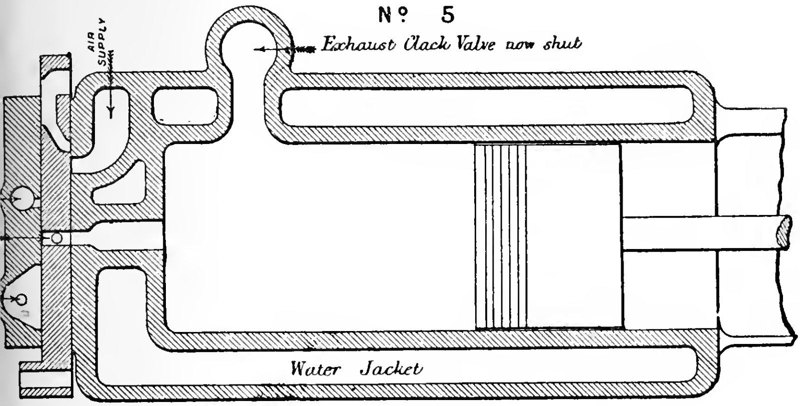


COMPRESSION AND IGNITION.

No. 4 shows the return stroke of the piston during its compression of the charge and, at this point, the light in the slide-valve just communicating with the charge, the air and gas supply being still cut off from the cylinder.

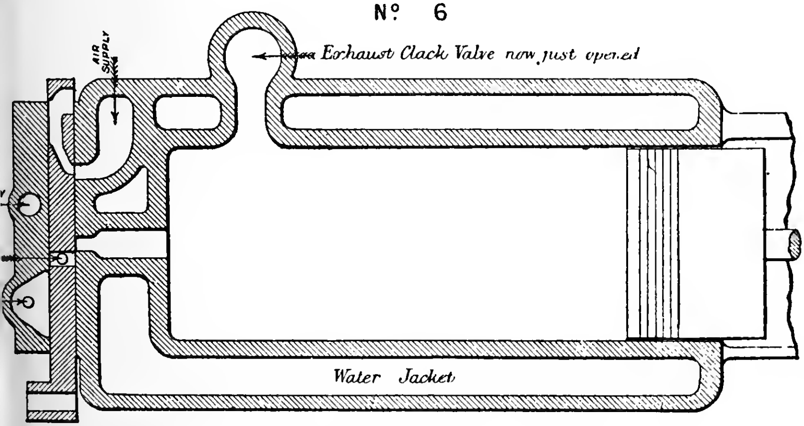
No. 5 shows the complete ignition of the charge with the consequent driving forward of the piston.

NO. 5



COMBUSTION

NO. 6

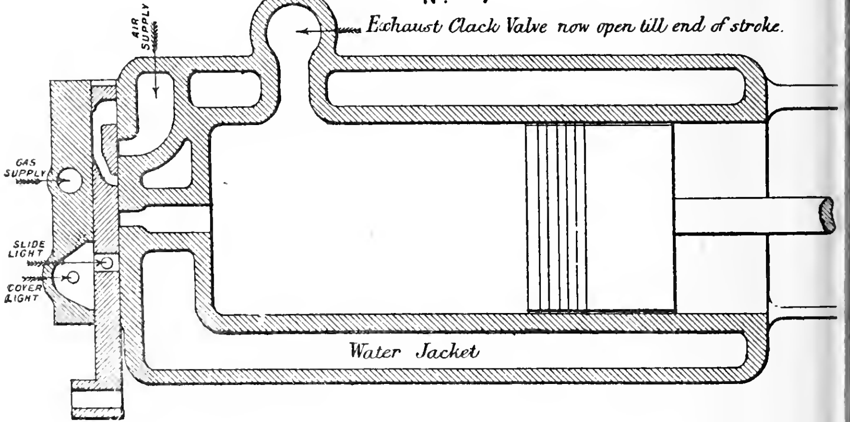


EXPANSION AND COMMENCEMENT OF EXHAUSTION.

No. 6 shows the piston again in its most forward position, the exhaust-valve being now open for the exit of the products of combustion.

No. 7 shows the piston again returning to expel the products of combustion, the exhaust remaining open until the completion of the backward stroke, which thus completes two revolutions of the fly-wheel.

No. 7



EXHAUSTION

These engines are deservedly in great favour, they work with a smaller consumption of gas than any other yet introduced, they are comparatively noiseless, their parts are few and simple. Beyond cleaning, they require little or no attention, and what is needed is of an unskilled kind, the arrangements for lubricating are simple, and for the greater part self-acting; but, compared with steam-engines, the consumption of oil for the cylinder is somewhat large, and may form an item to be taken into consideration in estimating the cost of working. The consumption of gas is at the rate of about 21 cubic feet per horse-power per hour; a more economical rate of working has been claimed for it in some instances; in fact, in an account given in an American paper some time since, the consumption was stated to be 11·7 cubic feet per horse-power per hour; but this is to be doubted, as it differs so widely from all experience in this country, and from what is claimed by the makers, that it seems probable that some error was made in estimating the amount of work performed.

The charge at the commencement of ignition is under a pressure of about 45 lb. per square inch, the maximum pressure exerted by the explosion is about 170 lb. per square

inch, and the mean pressure during the whole forward stroke about 70 lb. per square inch.

An engine of this construction has been made as large as 70 horse-power, it being a compound engine, with two high-pressure and one low-pressure cylinders; and it is now proposed to make one of 100 horse-power, but it seems doubtful whether gas-engines of such large sizes can be advantageously adopted, except under very special circumstances.

Another form of gas-engine, called the "Minerva," is made by Messrs. H. S. Cropper and Co., of Nottingham; it is of the horizontal type, and resembles the "Lenoir" engine in many of its details. The explosive mixture of gas and air is admitted alternately on each side of the piston, but there is no provision for compressing the charge. As first made, the explosions were effected by a battery, but, in later improvements, this was replaced by a thermo-electric pile heated by a gas jet. As might be expected, from the non-compression of the charge the consumption of gas is greater than in the engines previously described, being at the rate of about 40 cubic feet per horse-power per hour.

Messrs. S. Clayton and Co., of Bradford, are also makers of a gas-engine, called the "Excelsior," which differs from the "Otto" engine in having a pump fixed to the under side of the working cylinder, the piston and rod of which are attached to the cross-head of the cylinder piston, and work in connection with it. The working cylinder is double the length of the stroke, and the mixture of gas and air is compressed into it by the pump; it can be fired at every stroke if required. The working piston on the return stroke forces out a quantity of the consumed gases, while, at the same time, it is receiving a fresh charge of compressed gas and air from the pump. The exhaust is closed before the completion of the stroke, so that the whole is compressed before being ignited. The valve is of a conical rotatory construction, and is made to revolve at one-fourth the speed of the piston. The engine works by first drawing in a quantity of gas and air through the first cavity of the valve, another cavity then comes into position, and, upon the return stroke of the pump piston, the mixture is forced into the working cylinder; the lighting cavity then comes round, and ignites the mixture, driving the piston of the working cylinder forward, and at the same time the piston of the pump is drawing in a fresh mixture of air and gas.

From the repeated ignition of the gas, in all these engines, a considerable amount of heat is developed, which renders it necessary that the cylinders should be jacketed and surrounded

with water for cooling them. It has been objected that this supply of water for cooling the cylinder would form a considerable item in the cost of working the engine where the water has to be purchased; but it need not seriously affect the expense, as by connecting the cylinder supply with a circulating tank, so that the water can be used over and over again, but little waste need take place.

The necessity for surrounding the cylinder with water and the heating of the same has been taken advantage of in another form of gas-engine, called the "Eclipse," made by Messrs. Simon and Son, of Nottingham. The principle of working with a compressed charge is adopted also in this engine, but the compression is effected in a separate chamber instead of in the cylinder. Both the cylinder and chamber are surrounded with water, which, however, is not allowed to escape or circulate, but is retained round the cylinder and in a vessel above it, and, from the communicated heat, steam is generated, which is used, together with the gas, to assist in working the engine. A series of tubes also run through the water vessel from the exhaust pipe, so that every means, as far as possible, are adopted for utilising the heat. When first started, the engine has to depend upon the force due to the explosions alone, but after working a short time, the steam comes to its assistance. With this utilisation of the waste heat it might be expected that an economy in the consumption of gas, as compared with the "Otto" engine, would be obtained, but this does not appear to be the case, as the consumption is given at from 21 to 27 cubic feet of gas per horse-power per hour, which lowest quantity is about what is required for the "Otto" engine; it would seem, therefore, either that no advantage is obtained from the utilisation of the waste heat, or that the mode of using the gas is not so good; but possibly a combination of the two systems would give improved results, although the construction would necessarily become more complicated. The "Eclipse" engine possesses at least one advantage, in requiring less lubricating material for the cylinder, in consequence of the use of steam with the gases.

Mention may be made of one more form of gas-engine, called the "Bischopp," which, although possessing no advantages over those already described, is remarkable for its simplicity and cheapness, and for the small sizes in which it is made, rendering it available for purposes for which it would otherwise be impossible to employ mechanical power. They are being made in sizes varying from one-half to four man-power. The engine consists of a base plate with the cylinder cast on it, and an

upper casting forming the stuffing-box and guide for piston-rod, and on which is also cast a bracket for carrying the shaft with fly-wheel; an eccentric is also fixed on this shaft for actuating the valve for the admission of the gas and air, and for opening the exhaust at proper portions of the stroke. The explosive mixture is admitted at the bottom of the cylinder, and is ignited by means of a jet of gas enclosed in a case at the back, the communication being by means of a small hole about one-third up the cylinder. The shaft is driven by a rocking motion arrangement of connecting-rod, worked from the head of the piston-rod, and attached to a crank at end of shaft. This engine differs from the others in not being surrounded with a water jacket for cooling the cylinder; to effect this a number of brackets are cast on the cylinder, by which the cooling surface is considerably increased and the heat abstracted by radiation, which keeps it sufficiently cool; but this expedient would scarcely be effective for engines of larger size. The consumption of gas is stated to be at the rate of 13 cubic feet per one man, or $\frac{1}{8}$ horse-power, so that, compared with other gas engines, it is by no means economical in its working, at the same time the simplicity of its parts and the varied uses to which engines of such small power may be conveniently applied, make it an interesting addition to the means of utilising gas for mechanical purposes; and there is no doubt that it may be economically and usefully employed in many cases.

Several other forms of gas-engines have been brought out, but they do not appear to possess any merits over those already described, either in principle or economical working. In all cases the power is produced by the explosion or ignition of gas diluted with air, and the chief improvement made seems to be due to the discovery that a greater proportion of air may be used under pressure with the consequent economy of gas, and a more gradual development of the force. This principle has been most successfully applied in the "Otto" engine, of which large numbers are now being used for every variety of work.

Many comparisons have been made between the cost of working steam and gas-engines, and it has generally been the practice to take the total expenditure in each case, including labour and fuel; but, although it may seem that this should give practical results, yet it may admit elements of uncertainty. As a gas-engine requires but little attendance while working, the results of the comparisons depend greatly upon what amount is estimated for this in the case of the steam-engine with which it is compared, and it may vary considerably under different circumstances. For a small steam-engine the cost of attendance

may largely exceed the cost of the fuel, but the proportion of cost for attendance will decrease as the size of the engine increases, while with a gas-engine it differs very slightly. It seems, therefore, better to compare the cost of the two fuels only; and, when this is done, it is not surprising that gas should show to a disadvantage.

On account of the large amount of heat which escapes unutilised, as well as by reason of the various other inevitable sources of waste occurring in the manufacture of gas, it cannot be expected that an economy would be effected by converting coal into gas for obtaining motive power in lieu of using the coal direct for that purpose; and the results, both of theory and experience, show in favour of the solid fuel. The cost of the fuel for a gas-engine must necessarily be greater than for a steam-engine, but gas-engines may nevertheless be advantageously and economically used in many cases, especially where the intermittent use of an engine is required. A gas-engine can be started or stopped at a moment's notice, and when not actually working there is no consumption of fuel; there is also freedom from all nuisance from dust, smoke, or ashes, and but little attention is required while working; in fact, gas-engines may be used in cases and places where the use of a steam-engine would be out of the question.

Nothwithstanding the unfavourable conditions under which gas has to compete with solid fuel for the production of motive power, the difference in favour of the solid fuel is not so great as might at first sight be supposed; for, even with steam-engines and boilers of the best construction, the loss of heat is also very large. The difficulty of admitting the proper quantity of air into a furnace for the perfect combustion of the fuel is increased by the varying quantities and conditions of the fuel in the furnace at different times; when an excess of air enters, the products of combustion are cooled by imparting a portion of the heat to the uncombined air, and if too little air is supplied, a portion of the fuel passes off imperfectly consumed, and such variations must necessarily exist constantly in every furnace. Another source of the loss of a large amount of heat with a steam boiler, is the temperature at which the waste gases pass into the chimney; assuming the temperature of the furnace to be 2400° Fahr., and of the gases as they enter the chimney 600° Fahr., 25 per cent. of the energy of the fuel is lost from this source alone. Again, the available heat from the water or steam is only represented by the difference of temperature between the boiler and condenser, or point of exit of the waste steam, and taking the temperature of the

steam at 250° Fahr., and of the condenser at 100° Fahr., only 66 per cent. of the total heat of the steam is utilised. If the steam could be raised to the temperature of the furnace and then worked expansively, generating power until it was reduced to the condenser temperature, a much larger proportion of its power would be available; but even supposing that this were possible, a large portion of the advantage would be lost on account of the high temperature at which the furnace gases would have to be conducted into the chimney. Some advantage is taken of the economy obtainable from the use of steam at high pressure and temperature in modern engines, but it has proved successful only within narrow limits, and the danger of working at very high pressures, together with the corrosive action upon the boilers, &c., seem to forbid the hope that it can be carried much farther than is done at present.

The theoretical value of steam as a motive power has been estimated with considerable accuracy, but it is well known how very far the practical results obtained differ from the theoretical. It is true that vast improvements have been made in the generation and application of steam, in proof of which it may be stated that, while formerly the consumption of coal was as high as 25 lb. to 30 lb. per horse-power per hour, engines and boilers are now made capable of doing the same work with $2\frac{1}{2}$ lb. of coal, or one-tenth of the former quantity; yet even this is very far from the theoretical value of the coal.

According to experiments made by Joule, the quantity of heat capable of increasing the temperature of one pound of water (weighed in vacuo and taken at between 55° and 60° Fahr.) by 1° Fahr., requires for its evolution the expenditure of a mechanical force represented by the fall of 772 lb. through the space of 1 foot.

Now, a pound of ordinary coal is estimated to develope in its combustion 12,000° Fahr. units of heat, which represent 12,000 $\times$ 772 = 9,264,000 foot pounds, which divided by 60 and by 33,000, give a force equal to 4·68 horse-power per hour due to the combustion of 1 lb. of coal, or less than $\frac{1}{4}$ lb. per horse-power per hour, as compared with $2\frac{1}{2}$ lb. per horse-power per hour required with the best modern engines.

The thermal value of coal gas has not been determined with the same accuracy as that of coal and other solid fuels; numerous experiments have been made, but the results show variations between 500 and 1000 thermal units developed by the combustion of 1 cubic foot of gas. Dr. F. W. Siemens has estimated that 1000 cubic feet of coal gas cannot develope more than 748,000 units of heat, or 748 units per foot, and this

estimate agrees nearly with others made by Mr. Vernon Harcourt and Mr. F. W. Hartley; the value will vary for different qualities of gas, but the highest value which our present knowledge seems to justify is 800 thermal units due to the combustion of 1 cubic foot of ordinary coal gas, and this multiplied by 772 gives 617,600 foot pounds, which, divided by 60 and by 33,000 gives $\frac{31}{100}$ths of a horse-power per 1 cubic foot of gas per hour.

Taking the theoretical values of coal and gas as before stated, a comparison may be made of their relative values which, for the purpose of obtaining more manageable figures, may be based on the consumption required for 100 horse-power as follows:—

A steam-engine requiring the theoretical quantity of $\frac{1}{4}$ lb. of coal per horse-power per hour, would require 25 lbs. of coal per hour for 100 horse-power, which, at 20*s.* per ton, would cost 2·68 pence.

A gas-engine developing $\frac{31}{100}$ths of a horse-power per hour with 1 cubic foot of gas, would require 322 cubic feet per hour for 100 horse-power, which, at 3*s.* per 1000 cubic feet, would cost 11·59 pence.

Calculations of the comparative costs of the two fuels may also be made by taking the actual quantities required by the best description of engines of their respective classes, as follows:—

A steam-engine consuming $2\frac{1}{2}$ lb. of coal per horse-power per hour, would require 250 lb. of coal per hour for 100 horse-power, which, at 20*s.* per ton, would cost 26·78 pence.

A gas-engine consuming 21 cubic feet of gas per horse-power per hour, would require 2100 cubic feet per hour for 100 horse-power, which, at 3*s.* per 1000 cubic feet, would cost 75·6 pence.

These calculations show the gas to be theoretically more than four times, and practically nearly three times, more expensive than coal when used with good engines and boilers, and, although there may be good reason to hope that the practical effect of gas will be considerably improved, yet, it does not seem probable that it will ever compete equally with solid fuel so far as the actual cost of the fuel alone is concerned; but this does not by any means show that gas-engines may not in many instances be the most economical, for if the cost of attendance, wear and tear, &c., are taken into account, a very different result is arrived at.

Many estimates, including these items, have been made, which show a considerable advantage in point of economy in favour of gas-engines; but so many details have to be assumed that such estimates appear to be misleading. As before pointed

out, where a large power is required to be used continuously, the cost of attendance is comparatively small; but, on the other hand, with a small steam-engine it seldom happens that one person's time is exclusively occupied in attending to it and its boiler, so that it would in most cases be unfair to the small steam-engine to calculate the whole time of one man in the cost of working it.

In a paper read before the North British Association of Gas Managers last year, Mr. F. T. Linton gave the results of his actual working at Leith with a 3½ horse-power gas-engine, and with a steam-engine of equal power for doing the same work, his estimate being 28*l.* 12*s.* 6*d.* for one year's working with the gas-engine, as compared with 57*l.* 6*s.* for the same length of time with a steam-engine, wear and tear and depreciation being omitted in both cases; but from the amount estimated for the cost of the fuel for the steam-engine, it would seem that it could not have been an economical one, and the amount given for attendance exceeds the total cost of working the gas-engine. Again, in another paper read before the American Gas Light Association, Mr. Ramsdell gives three comparative estimates between gas and steam-engines, which show the steam-engines to be respectively seven, six-and-a-half, and three-and-a-half times more costly in working than gas-engines. These estimates were doubtless made with every care, and may be correct for each particular case, but they show that it is impossible to frame a comparison which shall be generally true.

Also as to wear and tear, our experience with gas-engines is so short that a reliable estimate of their durability and cost for repairs cannot be given; but present experience seems to show that, from the simplicity of their parts, and the absence of boilers, gas-engines should be by far the most economical under this head.

In regard to first cost, the prices at present charged for the best class of gas-engines are high, considering their simplicity, and they will probably become cheaper; but, at the same time, if compared with first class steam-engines, to work economically, gas-engines will be found the cheapest even at present prices.

For the reasons before given, no attempt has been made in this paper to frame a complete comparison between the cost of working gas and steam-engines; but it may be asserted that, for small sizes, gas-engines will, in all cases, be found the most economical, and that, even with larger sizes, if the same economy cannot always be maintained, circumstances will, in many cases, render them the most advantageous and convenient.

DISCUSSION.

Mr. F. W. Hartley said that he wished only to make a few remarks on two questions which had been raised in the paper, but he would first say that he perfectly agreed with Mr. Gandon that gas-engines ought to be as simple as possible in construction. The first question was, the advisability of attempting to utilise steam (generated by the combustion heat of gas) in the same cylinder or chamber in which a mixture of gas and air was exploded or burned. He had been led to form a pretty decided opinion that it was a mistake to attempt to utilise the waste heat in such a manner, as the presence of steam could only tend to lower the temperature of combustion, and thereby diminish the degree of expansion of the gases; besides which, the specific heat of steam was more than twice that of the gases of combustion, and therefore to produce the same degree of expansion twice the amount of heat was needful. An ingenious engine had been made, with which it was sought to utilise the power of the steam generated in a water vessel by the waste heat; but, in certain trials with that engine as against one of the same nominal power of the Crossley kind, he found that the first burned about 40 cubic feet per horse-power per hour as against about 25 cubic feet for the latter. Possibly the engine in question had since been improved, and those now made needed less than 40 cubic feet per horse-power, as Mr. Gandon had stated. He (Mr. Hartley) knew nothing from practical experience about the wear and tear of gas-engines, but apparently these were but trifling.

The next question was the heating power of coal gas. It was a fact that the power was not absolutely known. If the power were calculated for London gas, from its composition as determined by the most eminent authorities, it would come out at about 598 British units per cubic foot, but with such gas he had in actual working (the gas being of the same gravity as the samples analysed) realised over 625 units. He could not go so far as some, and say that its power was over 700 units, but he certainly was inclined to believe that such was the fact. During the last twelve years the thermal power of London gas had scarcely varied, for experiments made by himself at that time, and recently under similar conditions, were quite concordant. He was surprised to hear that Dr. Siemens (if he had understood rightly) had put the thermal power of gas so high as 830 units; for he could not think that point had ever been reached

with common gas. Some years since he (Mr. Hartley) had made some experiments in heating water with mixtures of gases, and was struck by the results, which seemed to indicate that mixtures of combustible gases, such as hydrogen and carbonic oxide, gave a higher thermal effect than was represented by the sum of the powers of the respective gases, but he had not been able to pursue the inquiry. If this were true, then the excess of the indicated over the calculated power would be accounted for.

Mr. ELDRIDGE said that the Royal Laundry at Richmond had lately fixed a gas-engine, and it had been noticed that when it was put to work it made the whole of the lights in the neighbourhood begin to jump. This would be a serious difficulty in a place where a large amount of gas was used, and he should like to have an explanation of it. The engine was of 12 horse-power. The mains were rather small, being about 3 or 4 inches.

Mr. SCHÖNHEYDER asked the last speaker whether he had more than one gas bag in use in connection with the engine in question.

Mr. ELDRIDGE said that he believed that there was only one bag.

Mr. SCHÖNHEYDER said that he thought that he could offer an explanation. The jumping was due to the engine taking the gas intermittently. He understood that the jumping had been avoided by a second bag being interposed. This acted like a regulator between the engine and the main.

Mr. ELDRIDGE said that he had wondered whether a large cylinder interposed, would prevent the jumping.

Mr. PERRY F. NURSEY said he gathered from the paper that the engines which were described were single acting. He should be glad to know whether anyone present had had any experience of double-acting gas-engines. He was aware that several inventors had endeavoured to produce a double-acting engine; but he was not aware that their efforts had been attended with practical success. At one time, a single-acting engine was advertised by Mr. Hurd, of Wakefield, about which he (Mr. Nursey) had made some inquiries, but he could not find out that such an engine was ever in existence. If Mr. Hurd, or anyone who knew anything about that engine, was present, he would confer a favour on the Members if he would give them information as to the existence of the engine. The author of the paper almost seemed to imply that for small powers, for the purpose of superseding steam, they had nothing

but the gas-engine. It occurred to him, that some eight or ten years ago he examined several excellent little gas-fired steam boilers, made by Mr. Jackson, and which were employed for hoists in some of the East India Dock warehouses, and at other places. He believed that there was still a number of them in use in various places, and that they were working very satisfactorily. These boilers were heated by means of Bunsen burners, and steam was got up very rapidly. A very small amount of gas was consumed during the intervals between the working, and the steam was always kept at a fair pressure, so that in a few minutes a sufficient working pressure was obtained. More recently, Mr. Hindley, of Bourton, Dorsetshire, had also brought out a similar arrangement of gas-heated boiler, and he (Mr. Nursey) believed that it was in considerable use. By these means steam power was available at a comparatively small cost, and was ready in a very few minutes when wanted, thus meeting the requirements of intermittent work. The arrangement was very useful, where space was an object, as in warehouses, and as there was no coal furnace, gas heated boilers were passed by insurance companies.

Mr. Somerville said that he for some years worked a gas-engine, which he put up some years ago in 1864. It was a three-horse engine of the Lenoir type, and was about the second one that was made in this country, and was by Barrett and Andrews, of Reading. It exploded the gas at both ends of the cylinder by means of a Rhumkorff coil, and a most troublesome thing it was, although it answered fairly well, but it was very expensive, consuming, he believed, about 70 cubic feet per horse-power per hour; but even then it was an economical machine, when used in gasworks. With reference to the trouble of his friend Mr. Eldridge, he believed that the jumping of the gaslights in the neighbourhood was only a question of the capacity of the service pipe supplying the engine. About 1864 or 1865, he put up a gas-engine for a newspaper office, and it set all the lights in the street jumping. The service pipe was only $\frac{3}{4}$ inch. He tried double gas-bags, but this did not remedy the evil. He then put on a 2-inch service pipe and got over the difficulty.

Mr. Duckham alluding to the statement in the paper that the Otto engine drew the gas into it in the upward stroke, asked what means were employed for drawing the gas in at starting. He understood it was afterwards drawn in by the momentum which was given by the fly-wheel. In doing work by steam, the amount of steam used was to some extent proportionate to

the amount of work done. In hydraulic machines, on the contrary, the amount of water-power used was ever the same per stroke and so not in proportion to the work done. He should like to know whether in the gas-engine the amount of gas consumed was in proportion to the work done, or whether there was the same consumption per revolution, whatever load was on the engine. Speaking generally, he regarded the paper of Mr. Gandon as a very valuable addition to the address which was given by their valued past President, Mr. Spice. Those who were owners of shares in gas companies, and also those who were employers of labour, might take comfort to themselves by such papers, which had shown them that notwithstanding the electric light, electric power machines, and other things about which they heard, gas was not dead yet, and that it was not likely to be without its full share of good, profitable employment. As an example, of interest to wharfingers and warehousemen, the paper stated that by the consumption of 13 cubic feet of gas per hour they could obtain the power of one man. This quantity of gas would cost between ½*d.* and 1½*d.* And there must be a person to look after the engine. But in the case of a hoisting machine, such as would be used on board ship and in warehouses, a boy might be obtained at the cost of about 4*d.* an hour, and the power of two or three men could be obtained at the cost of about 3*d.* an hour in addition, making a total of 7*d.* against 1*s.* 3*d.* for hand labour. It appeared to him that instead of there being no employment for gas, the field for it would enormously increase.

Mr. Light referred to a point alluded to by Mr. Duckham. As far as he remembered, there was nothing said in the paper with regard to the starting of gas-engines; yet this was a point which was generally found to be of considerable practical importance. Owing to the intermittent action of the gas, the engines required manual assistance in starting. At least, he found this to be the case with the smaller ones, but would be glad to know whether any mechanical means had been adopted as a substitute for manual power in the case of larger engines.

Mr. Bernays, referring to the application of gas-engines to hoists and cranes, said that he did not see how a man could start the engine by pulling it round by hand when there was a load on it to be lifted. He would like to ask Mr. Gandon, or any makers who might be present, how the machinery was arranged in such a case, as he understood that some of the engines were used for cranes. He should like to ask Mr. Gandon another question. In the case of the original Otto gas-

engine, the piston was driven out, and a vacuum was produced behind the piston, which pulled it back again and turned the wheels round. He wished to know whether a similar vacuum did not arise behind the piston in the present Otto engine, and probably in all engines using gas explosively. Had any diagrams been taken to ascertain whether, after the explosion was finished, a vacuum was produced behind the piston, so adding to the power which had been produced by the explosion? Something had been said about a compound gas-engine. He wished to know how that was to be worked, because the moment the explosion was finished, even with the compressed air in Otto's horizontal gas-engine, there was actually no power to go into a large cylinder after it had done its work in the small cylinder. In respect to the engine in which the heat of the gas was made use of to produce steam, which was referred to by the author as the Excelsior engine, theoretically, this looked a very tempting subject, and no doubt many persons had been exercising their minds to find out some means for utilising the waste heat which would otherwise go away in simply warming the engine. But, as Mr. Hartley had just pointed out, the presence of steam in the cylinder would render imperfect the action of the explosion. It had, however, occurred to him (Mr. Bernays) that the steam might be used in another cylinder in combination with the first cylinder. He wished to ask whether Mr. Gandon, or some of the makers, might be able to tell them the best kind of oil to use for gas-engines, for this was a subject requiring very special attention, it being desirable to prevent the engines wearing away too soon. He put up one of the very small engines about fourteen or fifteen months ago. It was of two men-power, and it had been working continually all day long and no repairs had yet been found necessary. He forgot what oil was used. He was now getting a two horse-power Crossley engine for another purpose, and it was for that reason that he wished to know what was the best oil to use.

Mr. Conradi said that the author had made a comparison between steam-engines and gas-engines, and shown that under certain conditions a gas-engine worked more cheaply than a steam-engine. He wished to know whether gas could be used under all conditions under which steam could be applied, especially as he had heard that gas engines could be applied for locomotive work, and that they could have gas-engines for working tramways. He should like to know whether the author thought gas could be successfully applied in that way.

Mr. R. P. Spice said that, independently of all technical questions, the gas world might take encouragement from what had been achieved in the way of adopting gas and air for motive power. Not long since they were threatened with extinction by an idea of utilising the Falls of Niagara, the cold water being converted into hot water by means of electricity; and that plan was propounded by a very great man indeed—no other than Sir William Thompson. He (Mr. Spice) did not wish to make invidious comparisons between rival inventors; he would rather encourage inventors of all gas-engines to go on and do their best; but he was glad to find that there was one engine better than all the rest, as the Otto appeared to be from what he had heard that evening. The question of expense and first cost might be almost put out of consideration in a great number of instances where gas might be used and steam could not. It was, however, a very encouraging feature, that a gas-engine which was capable of very extended application, and resulting in extreme convenience, could be obtained at a moderate cost. Steam had to be supplemented in a great many cases in the present day by gas, and, as a gas-man and one interested in the prosperity of gas undertakings throughout the length and breadth of the land, he rejoiced at what had been accomplished, and he felt thankful to Mr. Gandon for his excellent paper on the subject.

Mr. Schönheyder said he should like to see some diagrams of the other types of engines besides that which had been illustrated. It would be very valuable to add them to the paper. The Otto engine was certainly the one which, according to universal opinion, had given the highest satisfaction, and the most economical results, both as regarded the consumption of gas and with regard to wear and tear and simplicity. Like all machines of course it had defects. One disadvantage it possessed was that it was a single-acting engine, and only did work at every alternate revolution, so at the most the explosion took place only once in every four strokes, and when the work was light the explosion took place only once in eight strokes, or once in sixteen strokes. This was a disadvantage which it would be very desirable to amend, if the improvement could be accomplished without increasing the consumption of gas or complicating the engine. This fault necessitated a size of crankshaft, connecting rod, and bed plate, which in a double-acting engine, taking gas at each stroke, would do just four times the amount of work. Messrs. Thompson, Sterne, and Company had lately tried to introduce a double-acting engine.

It took in gas at every stroke, and at both ends of the cylinder, which it seemed to him was the right thing to do. The consumption of the gas in the Otto engine was about 20 cubic feet per horse-power per hour for small engines, but for larger ones the makers would guarantee less. He believed that as little as 15 cubic feet had been obtained. The consumption of oil was great. It would have been very interesting if the author could have given them some data as to what the consumption really was, because, no doubt, that was an important point in the cost. It would also have been interesting if the author could have given a diagram taken from the engine. Diagrams had been taken, and he (Mr. Schönheyder) thought that he could sketch one roughly on the blackboard. It would answer the question of Mr. Bernays, whether there was any vacuum formed under the piston after the explosion of the gas. There was no such vacuum formed. The pressure rose to about 100 lbs., and gradually fell, so that the diagram very much resembled one taken from a steam-engine in which the steam was wire-drawn and fell down at the end of the stroke to about atmospheric pressure. As to the starting of the gas-engine when it was used for a hoist, it was started before the weight was put on, and allowed to run light, and it only consumed gas in proportion to the amount of friction, taking in gas at perhaps every tenth or twelfth revolution, and the consumption when running light was exceedingly small. Mr. Gandon had made a comparison of the cost of fuel for steam-engines, with the cost of gas for gas-engines. However, he (Mr. Schönheyder) did not think that it was quite fair to compare simply the fuel. The cost of the engines, wear and tear, depreciation, the cost of cleaning the boilers, and the cost of attendance, ought to be compared. In the boiler of a steam-engine the combustion of fuel might be very perfect. They need not lose more than 20 per cent of fuel in producing a draft in the chimney. It was in the imperfect steam-engine that the loss was very enormous. The best ones did not return more than about a tenth of the power which ought to be returned for the heat which they received, and the steam-engine and boiler as compared with the gas-engine were enormously expensive for the amount of fuel which was consumed. For this reason the cost of the engine and boiler and all the other expenses ought to be taken together. He fancied that there was some little error in speaking about the cost of steam working through an engine. It was stated that the temperature of the steam was 200 or 300 degrees, and that there was some 100 degrees wasted. But to the 200 degrees

must be added the latent heat which had been put into the water to make it steam, and the total would amount to about 1000 degrees, out of which only a small amount was utilised, the rest being thrown away into the condenser or into the atmosphere. With reference to the number of units of heat obtainable from a cubic foot of gas, he had been rather surprised to hear lately that Dr. Siemens considered 748 units to be the theoretical maximum. He had an account of some experiments in which it was stated that over 600 units could be obtained in practice. He was told that several makers of the well-known "Geyser" for the instantaneous heating of water, guaranteed as much as 800 or 900 units of heat per cubic foot of gas. Whether they fulfilled the undertaking, he did not know. The maker of the gas-stove which had been recently brought out by Dr. Adams in Glasgow, stated that the heat obtained per cubic foot was equal to 900 units. Mr. Nursey had referred to an engine and a gas-heated boiler. That was a most extravagant apparatus as compared with the ordinary steam-engine with boiler heated by solid fuel, or the gas-engine. Although the apparatus was very handy and well worth using before the present gas-engines were brought out, it would be very undesirable to use it now, for it would require about six or eight times as much gas as the Otto gas-engine for the same amount of work done.

[The speaker then drew on the board an indicator diagram obtained from the Otto gas-engine.]

Mr. WALMISLEY said, that the chief merit of a gas-engine, independently of the question of first cost, was the readiness with which it could be set to work and its comparative economy in working expenses. He should like to ask the author up to what limit of horse-power, according to his experience, they might economically use a gas-engine in preference to a steam-engine, and again when the horse-power of a gas-engine was spoken of, were they to regard the horse-power as entirely effective? In a steam-engine (as is well known) only a certain percentage of the boiler power was considered to be developed in actual working.

Mr. S. J. BALL asked whether it was usual when a gas-engine was fixed to give notice to the local officer of the company from which the gas supply was obtained? His experience of gas-engines was very limited. Only three had come under his notice; in each of those cases the defective gas supply had militated very much against the success of the engine. In one of these cases the service pipe was enlarged from $\frac{3}{4}$ inch to $1\frac{1}{2}$ inch, and he had not heard a complaint since.

He recommended that when a gas-engine was about to be fixed, the officer of the gas company should have notice given to him. It would materially assist him in the performance of his duties, and most assuredly assist the successful working of gas engines generally.

Mr. SCHÖNHEYDER added, in reference to the question of the wear and tear of gas-engines, that after they had been at work for some time, the makers would readily buy them back at a very small reduction in the original cost.

Mr. JAMES L. CHAPMAN said that it seemed that they had overlooked the Bischopp engine. However much the steam-engine might interfere with the Otto engine, he did not think that it would with the Bischopp. This engine took a place which was not held by any other, for it would do the work of a man. He believed that in country districts the small engines would be most required.

Mr. PENDRED said that it would be well to bear in mind that there was a very great distinction between the Otto engine and all other engines which acted explosively. If they analysed the Otto engine and considered what its action was, it would be found that it was far more a hot-air engine than a gas-engine, and that the work really done by the gas was not explosive, but gradual work done as it would be done in a hot-air engine. That appeared to be very clearly shown by Mr. Schönheyder's diagram. It was found that instead of the pressure flying up at once, as when only the proper equivalents of air and gas were mixed in order to produce the effect required, the pressure accumulated while the piston was moving, during which time combustion was going on quietly and the air was being expanded. There was a remarkable analogy between the two classes of engines and the two systems employed in artillery, that of using quick-burning powder, and that of using slow-burning powder. This difference had been very clearly shown and had been reduced long since to diagrams. Perhaps the diagrams were not familiar to everybody and, therefore, he would show what they were.

[The speaker then drew and explained some diagrams on the blackboard.]

It was objected when the slow-burning powders were being used, that sufficient velocity would not be got in the shot, for it was maintained that a high pressure was absolutely essential to produce a high initial velocity. It was found in practice that such was not the case, and that a higher initial velocity was obtained from the slow-burning powders, because, as Mr. Schön-

heyder has shown in his diagram, the work done on the shot was really represented by the areas of the diagrams of energy. The area with slow-burning power was two or three times as great as the other. It occurred to him that they had got precisely the same thing in the Otto engine, and he believed that it was a point which was very much in favour of the engine, that from a given expenditure of heat, or from a given expenditure of gas, they really got a far larger diagram than in the other engines; and that was one of the reasons why the Otto engine was so much more economical than any other. He wished to ask Mr. Gandon whether it was found in practice that the products of combustion set up a corrosive action upon the engine. The products would be mainly acidulated water. For many years he had carried on a series of experiments in heating with gas, and he had found, in the case of the Bunsen burner, that when the products of combustion were led away through pipes and condensation of the water took place, the destruction of the pipes was very rapid, at all events when metropolitan gas was used. Whether this arose from the sulphur in the gas, he did not ascertain.

Mr. R. P. Spice said that the remarks which had been made by a former speaker, showed that the disagreeable disturbing effect produced upon the gaslights in the vicinity of a gas-engine might be avoided by the use of a large service pipe. This brought to his mind an incident which occurred to him thirty or forty years ago. A gentleman at whose house he was dining, complained that he could not get gas enough. Upon examining into the matter, he (Mr. Spice) found that his host was being supplied through a $\frac{3}{4}$-inch service pipe, and had only a three-light meter, and yet there were twenty-six lights burning in the house that evening. He should not have been surprised if the gentleman had added a gas-engine.

Mr. Baldwin Latham said that he had recommended the use of the gas-engine in two instances during the past year for the pumping of sewage. In one instance, the gas-engines were to be used in a place where nobody should know that there was a sewage pumping station. It was essential, under the circumstances, that the engines should be under control, and could be regulated to pump when there was anything to pump, and to be put out of gear when there was nothing to pump. On consultation with the makers, he found that it was necessary that the engine should be kept constantly going; but by means of a float arrangement, when there was sewage to pump, the driving band could be shunted on to the pulley driving the pumps, and at

the same time an increased supply of gas could also be admitted to the engine. When the sewage tank had been pumped out by a reverse operation the gas was partly shut off, the pumps could be put out of gear, and only a small quantity of gas was required to keep the engine going until it was necessary to again start to pump. In one of the cases where he had recommended the adoption of a gas-engine where small pumping power was required, the whole machinery could be put under the street, and no land needed to be expensively acquired, as would be the case if a steam-engine were used, and so by using a gas-engine the authorities saved the expense of going to Parliament to acquire a site for a pumping-station. No boiler or chimney was required with gas-engines, and all the arrangements could be easily carried out in a small chamber below the street, and as the machine only needed attention two or three times a day for oiling, and to be thoroughly cleansed once a week, its use in places where steam could not be adopted without great cost in acquiring a site would commend the use of this engine, and no doubt it would, in the future, be extensively used where small power was required for pumping purposes.

Mr. Gandon, in reply, said that he ought to feel very much flattered at the interesting discussion which his paper had brought forth. He had endeavoured to avoid the advocacy of any particular engine, and if he had referred more especially to the Otto engine, it was because he had had more experience of that than of any other kind; but there were several others which, considering the details of their construction, ought to be capable of doing equally good work. Mr. Hartley had said that he had tried the one in which steam was generated for working it in connection with gas, and his observations evidently corroborated the information which he (Mr. Gandon) had received, that no advantage was obtained from the steam, but he could hardly understand the cause of this. A gentleman had suggested that the steam might be available if it was used in a separate cylinder, but such an arrangement would make a very complicated engine and would do away with one of the charms of the gas-engine, namely simplicity. Mr. Hartley had misquoted him in saying that Dr. Siemens attributed 830 thermal units of heat to a cubic foot of gas. The amount was 740 units, and he really thought that that was as much as was attainable. He believed that if a calculation was made from the chemical constituents of coal-gas, it would be found simply impossible to obtain 1000 units, as had been claimed for it by some persons; but if those gentlemen could show how to obtain such an amount,

engineers would be very much obliged to them. Mr. Eldridge's question as to the jumping of lights had been already answered, but the jumping might not be entirely due to the smallness of the service. He (Mr. Gandon) was inclined to think that the main also might be too small for the duty which it had to do. He should certainly think that a small gasholder interposed would lessen the oscillating effect, and that even a gas bag would remedy it to a certain extent. The gas-engine which he used worked with a day pressure of $\frac{8}{10}$ths of an inch, and he fully believed that the gas-burners would burn at the same time on the same service. The engine was a $2\frac{1}{2}$ nominal horse-power, and the service was $1\frac{1}{4}$ inches. Mr. Nursey had referred to the engines being single-acting. It was certainly so far objectionable that they required to be larger on that account, and anybody who had seen them would say that, for the horse-power which they represented, they were somewhat large in appearance; but if better results could be obtained from a single-acting engine than from a double-acting one, he could not see that there was any particular objection to be raised to their being single. He had stated in his paper that there were double-acting engines made by some makers, but he had not seen them himself. There was a double-acting engine of the Otto type of 70 horse-power, with high and low-pressure cylinders. As to gas-fired boilers, one of the speakers had replied that they would be rather expensive things, and he (Mr. Gandon) must say he did not think that gaseous fuel could compare with solid fuel in any way, if it was to be used indirectly. With regard to Mr. Duckham's question, the consumption of gas in the engine was certainly proportionate to the amount of work performed, for if the engine was not doing work the fly-wheel would make a considerable number of revolutions without drawing in more gas. It was only when the momentum of the fly-wheel began to decrease, that the governor would come into action and more gas be drawn into the engine. As to Mr. Light's question, he (Mr. Gandon) was afraid that it would be impossible to make gas-engines self-starting. If, however, they were allowed to run while not doing any work, the consumption of gas during that time would be so small that he did not think the cost would be a drawback to their use. Mr. Bernays had asked whether there was any vacuum behind the cylinder in the Otto engine, and Mr. Schönheyder had already replied to that question. There was no such vacuum. As to the amount of oil, he (Mr. Gandon) found that, in his $2\frac{1}{2}$ horse-power engine, half a pint of oil was

used in four hours. The makers recommended sperm oil or oil of equally good quality, and he thought it probable that if care were taken it might be possible to do with a smaller quantity than he had mentioned. He understood Mr. Conradi to ask whether gas could be used instead of steam for a locomotive. Gas was used for lighting carriages, and it might be possible to work locomotive engines by means of gas, especially if the gas was compressed into cylinders at high pressure. Whether this would be economical he could scarcely say. The consumption of gas in the Lenoir engine was about 70 cubic feet per horse-power per hour. He had seen some diagrams taken from the Otto engine, and they were very similar to those drawn upon the board by Mr. Schönheyder. Mr. Schönheyder had stated the consumption to be only 15 feet per hour. In the case of the 2½ horse-power engine with which he (Mr. Gandon) had experimented, the consumption was about 21 feet. The makers themselves stated the consumption to be 22 or 23 feet. He agreed with Mr. Schönheyder that it was not fair to compare the fuels alone, but he could not find a satisfactory means of making the comparison in any other way. He had no doubt, however, that the small gas-engines were more economical than steam-engines. The wear and tear was remarkably small. He had had one in use for nearly three years, and the only repairs which had been necessary consisted of the occasional refacing of the slide-valve. This had a considerable bearing surface which was liable to wear, and so to allow of the escape of the gas. The operation of refacing was, however, a simple one. He could scarcely reply to Mr. Walmsley's question as to the number of horse-power up to which gas-engines could be used effectually as compared with steam-engines, but his impression was that the smaller they were the more economical they were in comparison with the steam-engine. He believed that with such high powers as 70 or 100, they would scarcely answer, unless there were some peculiar circumstances which precluded steam-engines. As to Mr. Ball's question, it was certainly desirable to consult the authorities of a gas company before fixing a gas-engine. He had had an experience somewhat similar to that which Mr. Light had related, with regard to the smallness of the service pipes. The fact was that people began, perhaps, with three lights, and afterwards increased up to thirty without increasing the service pipe. Mr. Chapman had referred to the Bischopp engine. There was one in the room, and he (Mr. Gandon) need not say more about it. To his thinking, it was certainly a most ingenious and simple thing, but it was not so economical

as the others. He should not wonder if they had ladies using the Bischopp engine for working their sewing-machines. He thought that Mr. Pendred was probably right in comparing the Otto engine to a hot-air engine. There was no doubt that the large amount of compression, and the large amount of air which was introduced into the charge, made the engine act very much as a hot-air engine. Much was due to the expansion of the mixture in the cylinder by means of the heat. The question whether corrosion was caused by the products of combustion, was answered by the statement which he had made with regard to the repairs which had been necessary to his own engine. There was a corrosive action on the valve, but not to an inconvenient extent. The makers laid great stress upon good oil being used. He believed that a great deal of the corrosion might be prevented if good oil was used and plenty of it. He thanked the meeting for their kindness and patience in listening to his paper and reply.

Mr. Horsley said that he had bought a gas-engine of 12 horse-power, which had been working some time. It could be worked up to 25 horse-power. One objection which he had to it was the speed at which it worked. He should say that in an engine of very large size, the wear and tear would be a very great consideration on account of the speed. The engine was working very well. The oil which was used for the engine was used over again for other purposes, such as screwing bolts and nuts. The author of the paper had not stated it made any difference to the engine whether the gas was rich in illuminating power or not. This engine had been going for a considerable time, and worked economically, although coal was very cheap in the localities in which the engine was at work. It consumed about 17 cubic feet of gas per horse-power per hour, and the cost was much lower in proportion than the cost of a steam-engine would be, if doing the same work and placed in the same position. The engine worked steady, and as well as a steam-engine would do, and left the engine man at liberty to do other work. He was not going into the question of heat, but certainly the cylinder got very hot, and the water came out extremely warm. The slide-valve had once required to be looked at, and was found worn, as in the case which Mr. Gandon mentioned. One advantage of the gas-engine was, that its use would be allowed in places where steam boilers would be objected to, and no objection was raised by the insurance offices. He hoped that some day they would have a gas-engine with rather fewer parts

about it than the Otto engine, which looked like a sewing machine. At the present time, when the explosion took place in the engine, this explosion sometimes had to produce three or four revolutions. He fancied that if two cylinders could be employed the engine might be made to work as slowly as was desired, and the percussion would be less; he was sure that they ought to thank Mr. Gandon for his valuable paper.

April 4th, 1881.

CHARLES HORSLEY, PRESIDENT, IN THE CHAIR.

ILLUMINATION BY MEANS OF COMPRESSED GAS.

By PERRY F. NURSEY.

However valuable coal gas may be as an illuminating agent under ordinary circumstances, as in streets and buildings, there are some conditions under which its use in a free state is attended with inconvenience and expense, whilst there are yet others where its adoption for lighting purposes is practically impossible. Under the first head comes the lighting of railway carriages, and under the second the illumination of ships and buoys or beacons. In all such cases the use of gas under pressure suggests itself, and, provided the attendant difficulties of compression, condensation, and regulation be satisfactorily met, and a high illuminating power be insured, no better lighting agent could be desired than ordinary coal gas. But although much has been done towards utilising coal gas, in this direction its application in practice is at present very limited, the ordinary gas in such cases having to be enriched. These applications are mainly confined to railway carriages. The question of the efficient and economical lighting of these vehicles is one which has occupied attention ever since railways were established. Of late years the question has become more and more pressing, and considerable ingenuity has been exercised in attempting its solution. The manifest deficiencies of the old oil lamp, long since led to the attempted adoption of coal gas at ordinary pressures on one or two lines of railway, and its use has been attended with a certain amount of success, still however leaving much to be desired. Mr. Newall, on the Lancashire and Yorkshire Railway, was the first to practically apply it in this way, and he was followed later on by the Metropolitan Railway Company; but the apparatus is so cumbrous and troublesome, that it is gradually being superseded by high-pressure gas. As an illuminator, ordinary coal

gas is of course far in advance of the oil lamp; but, besides the cumbrous gasholders on the tops of the carriages which its use involves, there are other equally, if not more serious objections. These are the comparatively short supply of light which at the best can be insured without renewal, the waste of gas in charging the holders on the carriages, and the frequency of that operation, all of which constitute drawbacks which it is very desirable to avoid.

Various attempts have been made during the last fifty years, by Portable Gas Companies, to supply isolated buildings, but they have all hitherto failed. One of those companies existed for several years in Paris, but as the local gas companies extended their mains to the suburbs, they gradually supplanted portable gas; and there is not now a company existing for the special purpose of supplying gas to houses and other buildings in bulk in portable form. It is, however, a question whether it would not answer the purpose of gas companies to undertake this service for the lighting of buildings beyond the range of their mains. As regards the use of gas under pressure, it is to be observed that there is nothing novel in the principle of compressing gas of high illuminating power into vessels specially constructed for artificial illumination. The novelty consists either in the apparatus employed, or in the method of application. The principle generally adopted is to compress the gas in stationary reservoirs, and from them to supply the cylinders on the carriages. The difficulty, however, which stood in the way of the practical application of this principle was that of properly regulating the pressure of the gas supplied to the burner so as to maintain a uniform pressure notwithstanding the reduction which was constantly going on in the reservoirs during consumption.

It was a long time before any satisfactory automatic regulating apparatus was devised. The usual mode of adjusting the supply was by means of a pointed steel screw working in a conical seating, which had to be regulated by hand, but as the pressure decreased by consumption, the light was continually decreasing after each fresh adjustment. This was found very inconvenient, and in course of time a self-acting regulator was devised. It is on this instrument that the uniformity of the supply of compressed gas depends, and upon which inventors have displayed much ingenuity; for while the pressure in the cylinders may be 150 lb. to the square inch at starting, it is reduced 15 lb. by every volume equal to the cylinder's normal capacity taken from it. Thus, if the cubical capacity of a

vessel be say 10 feet, and 100 feet of gas be compressed into it, the internal pressure will be 150 lb. to the square inch, and every foot of gas consumed will reduce it by $1\frac{1}{2}$ lb. The gas at the burner, however, has to be maintained at the uniform pressure of a column of water only an inch high, and to give a steady flame from the highest or full pressure down to the lowest or to the almost exhausted cylinder, and so that only about a cubic foot per hour may be consumed.

During the past two or three years the author has had the opportunity of inspecting the working of three different systems of railway carriage lighting by means of compressed gas. The first of these is that of Mr. William Sugg and Mr. F. W. Clark; the second, that of Mr. George Bower; and the third, that of Mr. Julius Pintsch. In the first and second systems, ordinary coal gas, enriched by means of hydro-carbon vapours, is used; whilst in the third, oil gas is employed. Mr. Sugg has also recently perfected a method of using cannel gas under pressure, which the author has not yet seen.

In the Sugg and Clark process, the illuminant consists of ordinary coal gas of 16-candle illuminating power, enriched with hydro-carbons under the influence of heat. Ordinary London gas is composed of about 94 per cent of hydrogen and marsh gas, and 6 per cent of hydro-carbon gases. The properties of the hydrogen and marsh gases are rather heat-producing than light-giving, so that the light-giving power is mainly due to the small percentage of the hydro-carbon gases present in the bulk. One of the richest of these latter gases is naphthaline, which, however, will of itself, under certain conditions, solidify, separate from the gas, and become deposited in the form of crystals, thus depriving the gas of the benefit of its presence as an illuminant. By the addition, however, of certain other hydro-carbons, Mr. Sugg found that the solidification of this naphthaline was prevented, and its retention insured in the bulk of the gas in the gaseous form. It is thus rendered available, together with the additional hydro-carbon gases, for raising the illuminating power of ordinary coal gas to a very high standard. In practice, the hydro-carbon illuminants are supplied to the ordinary gas at such a temperature as to prevent the deposition of the naphthaline which always occurs in cold weather. These extra illuminants are obtained either from naptha or light petroleum oils. The hydrogen and marsh gases in the coal gas have a great affinity for the rich hydro-carbons, of which they absorb a certain definite quantity, which they are stated to retain permanently, after being subjected in combination to a

temperature of from 600° to 800° Fahr. The ordinary gas thus highly enriched, passes on its way from the commingling apparatus to a gas holder or receiver, in which it is stored for use under a pressure of about 120 lb. per square inch. In this way, the ordinary 16-candle gas becomes transformed into 40-candle gas, its illuminating power being thus more than doubled in proportion to its bulk.

In the early part of last year the author inspected the arrangements for carrying out the practical application of this principle by Mr. T. C. Hersey on the part of the Gas Light and Coke Company, in connection with the Great Northern Railway at King's Cross. One of the gas company's stations conveniently adjoins the railway at the latter place, and there the apparatus for enriching and compressing the gas was put up. The author was also afforded the opportunity of inspecting the light in use in one of the Great Northern carriages which had been fitted up by Mr. Sugg. The carriage apparatus consists of four iron store cylinders or reservoirs, each 15 feet long and 8 inches in diameter, and placed on the roof of the carriage. From these reservoirs small pipes convey the gas to the lamps, which are fitted with regulators or governors, and supplied with the necessary arrangements for controlling and economising the supply of gas. The governor is so arranged as to maintain a perfect control over the pressure and not to be in any way liable to derangement. It consists of a leather gas holder, fitted with a metallic cover, to the top of which is attached a hollow rod terminating in a fork. In the fork works a long slotted lever, the opposite end of which is attached to a screw in such a manner that the screw is screwed up or unscrewed as the lever rises or falls. This screw is placed behind a cylindrical valve, terminating in a point of ivory. The base of the valve is acted on by a spiral spring to bring it away from its seating. It therefore follows that as the gas holder rises and screws up the screw against the back of the valve, the opening is more or less closed, and *vice versâ.*

The lamps are of nickel silver and ornamental in appearance, the rim around them being perforated, and forming an efficient ventilator for each compartment. The vitiated air is drawn off by the induced current caused by the lamp flame, and escapes by way of the roof. The supply of gas to the carriage is conducted from the adjacent gasworks by a pipe laid underground to the railway platform, the connection for the supply to the carriage being made by means of a flexible hose. The gas is stored under a pressure of from 50 lb. to 70 lb. per square

inch in the reservoirs, and such is the durability of this small bulk, that the carriage has made the journey to Leeds and back with one charge of gas, the lamps in each of the four compartments being kept burning all the time. The journey has been several times repeated with the same results during severe weather, several inches of snow on the roof failing to affect the gas in any way. The gas, in fact, has been allowed to remain in the reservoirs on the carriage for a week exposed to the cold, without any condensation or deterioration occurring.

This experiment in carriage lighting was made by permission of Mr. Oakley, the superintendent of the Great Northern Railway, and so far as it went the author understands it to have succeeded. M. Oakley, however, desired to make the trial with gas made from cannel coal, which does not require enriching, and this is now being carried out at the Victoria Station of the London, Chatham, and Dover Railway. There the Gas Light and Coke Company have erected compressing apparatus for the supply of trains with cannel gas, the enriching works at King's Cross remaining in abeyance pending that experiment. A train of eleven carriages on the Great Northern Railway has been fitted up for burning the compressed cannel gas, and is now running. The train travels over the metropolitan extension of the London, Chatham, and Dover Railway to Victoria, where it takes in its supply of gas as required.

The arrangements for carrying out the Sugg and Clark process of enriching ordinary coal gas at King's Cross have been modified and improved upon by Mr. Sugg, and the new apparatus has been erected at Swindon under Mr. Charles Botley, the gas engineer to the Great Western Railway Company. The object is to light the carriages on that line with the ordinary gas of the company compressed and enriched. The apparatus at Swindon consists of a double retort enclosed in a fire-clay furnace, one retort being placed above the other. The two retorts are connected by a vertical pipe which reaches nearly to the bottom of the lower retort, its top in the upper retort terminating in a perforated hollow sphere. The upper retort is filled with small fragments of scrap iron. The retorts being heated, the gas to be enriched is delivered into the upper retort by means of a pipe passing through its cover. Within the gas supply pipe passes a tube through which the enriching oil is fed into the retort. The oil falls on a splash-plate, and is distributed down the sides of the upper retort and amongst the fragments of iron. The oil is thus evaporated, and the gaseous hydrocarbons are combined in proper proportions with the

ordinary coal gas, which is thus enriched to the required extent. A pipe from the top of the lower retort conducts the enriched gas to a gasholder. There are arrangements for regulating the supply of oil to the retort, for governing the pressure, and for registering the quantity of gas treated.

The carriages are each fitted with two cylinders 20 feet long and 12 inches diameter, constructed of tinned steel plates, and carried on the roof. They each have a capacity of 20 cubic feet, and they are supplied with gas at one end of the carriage through a charging valve and by means of a hose in connection with a pipe from the reservoir of compressed gas. At the other end of the carriage is a shut-off valve through which the gas passes from the cylinder to the governor, which has already been described. From the governor the gas passes into a by-pass cock—which can be turned on or off from either side of the carriage—and thence to the main service, which is laid along the top of the carriage. There is an arrangement for supplying a flash light. The lamp resembles externally an ordinary oil lamp, in fact ordinary oil lamps can be converted to this purpose. It is designed to meet all the special requirements as to ventilation, &c., and is stated to be in all respects an efficient railway lamp.

The next system for notice is that of Mr. Bower, who about three years since laid before the Great Northern Railway Company a scheme for lighting their trains with compressed oil gas, and he fitted up a carriage which it is stated gave every satisfaction, except that the company objected to the manufacture of the special oil gas and to its attendant expense. This being so, Mr. Bower and his eldest son set to work to see what they could do with common gas by compressing it, and raising its illuminating standard. After three years of careful experiment they have succeeded in producing a light of high illuminating power. Common coal gas is used, and it is carburetted under the influence of heat before it reaches the burner. A Great Northern composite carriage has been fitted upon Mr. Bower's system and the author recently made a journey in it, the light given being perfectly satisfactory. The carriage has been taken over by the Great Northern Company, and is now running between London and Peterborough.

On the top of the carriage are fitted two wrought-iron cylinders, each being 9 inches in diameter and 16 feet long, and they are connected with each other. These cylinders are proved to 500 lb. per square inch, the working pressure being

from 100 to 150 lb. Their normal capacity is about 13 cubic feet. If ten equal volumes be forced into them they will then contain 130 cubic feet of available gas, and the pressure will be 150 lb. per square inch. The gas used is such as can be obtained at the principal stations at a cost of say 3*s.* 6*d.* per 1000 cubic feet; and at this high pressure it is admitted into a regulator invented by Mr. A. S. Bower, and its pressure is automatically reduced by this instrument so that a constant uniform pressure is maintained at the burners equal to a column of water an inch high.

The regulator consists of a rectangular cast-iron box, the front end of which is removable, two of its sides being formed with openings closed with wrought-iron plates. Between the box and these wrought-iron sides are leather diaphragms, which also form tight joints with all sides of certain plates, forming flexible hinges at one extremity, and therefore enclosing gas-tight spaces, with the exception that holes are provided through the sides communicating with the external atmosphere. The hinged plates are connected together by a system of levers, one of which, together with a small crank and its counter-balance, oscillates about a fixed point as the plates move about their hinges. The crank is connected by a flat link to a valve, the tail-piece of which is triangular in section, so as to allow gas to pass into the regulator when the conical head of the valve is raised off its seat. A flat spring is applied to one of the hinged plates, tending to cause the plate to move inwards about the hinge. The spring is riveted to one of the sides, and its tension is varied by a thumb-screw, which also varies the burner pressure as required, a lock-nut being added to prevent the thumb-screw from moving after the desired pressure at the burner is obtained.

The apparatus operates in the following manner: When the high pressure gas enters it exerts a pressure exceeding that of the atmosphere, and therefore tends to move the hinged plates outwards towards the holes against the spring. The plates, acting through the intervention of the levers with the crank, lower the valve upon its seat, and *vice versâ*, according to the requirements of the lights which are burning, and drawing off gas at the low pressure outlet. The valve is placed so that the receiver pressure tends to close it. When the receiver pressure is high, the valve occupies a lower position than when the pressure is reduced, so as to keep the flow of gas constant. Equilibrium, however, is maintained, because extra pressure exists upon the head of the valve, which is counter-

acted by the extra compression of the spring. The whole of the working parts of the apparatus are balanced, and work in opposite directions, so that no shaking can influence the valve. A perfectly uniform burner pressure is thus maintained under all circumstances so long as any gas above this pressure remains in the receiver. The pressure is constantly varying in the cylinders, getting less and less as the consumption goes on, every 13 feet consumed reducing it by 15 lb.; but it is stated that the regulator never fails in the delicacy of its action, and whatever may be the pressure desired, when it is once set, it maintains it without the slightest variation.

From the regulator the gas passes to the roof lamps, and here it is that the greatest difficulty has been experienced in order to make a consumption of from 1 to 1½ cubic foot per hour of common coal gas efficiently light the compartment of a carriage so that passengers might be able to read with comfort. Great, however, as the difficulty was, it has been overcome. The author is not at present permitted to state the precise means by which the problem has been solved, as the patent has not yet been completed.

With regard to cost, Mr. Bower states that from careful experimental trials, extending over a considerable period, he finds that the total cost of the gas and compressing it, and of the liquid used for carburetting it, does not exceed 6*s.* 8*d.* per 1000 cubic feet; and as from 1 to 1¼ cubic foot of it is stated to efficiently light a compartment, it follows that a carriage fitted up as described would allow four lights to be burning for from twenty-five to thirty hours each for somewhat under a penny for each light for ten hours. There are other special arrangements for turning down the gas so as to leave only a flash light during day-time when there are no tunnels to run through, and the whole is under the control of the guard, so that he can turn the four lights on or off at pleasure.

Amongst others who have endeavoured to utilise ordinary coal gas for illuminating railway carriages is Mr. Julius Pintsch, a gas engineer of Berlin, who, some ten or twelve years since, experienced all the difficulties and objections incidental to its use in this respect. He then tried to use it under pressure, but finding in that condition that its illuminating power was greatly lowered, he experimented with the gases produced from shale oils, and in course of time perfected the system which has next to be described. This system consists in distilling the refuse of shale oil or other similar matter, and in storing and using, under considerable pressure, the gas produced from it.

This gas is of high illuminating power, and is stated to be of a thoroughly permanent character. These are very important conditions, and were they not fully attained the system would doubtless long since have proved a failure instead of being, as it is, a great success. The gas is produced at works in each case conveniently situated with regard to the railway adopting the system. These works vary in size according to requirement; but the general arrangement, and in fact the details, are similar in all cases, subject only to variations necessitated by varying local conditions. The author has visited several of these works, and will take for description those of the Metropolitan Railway at Hammersmith, which are very compactly arranged and complete in their character.

The gas is produced from shale oil refuse, which is obtained from the paraffin works in Scotland, although any fatty matters can be used. There are four coupled furnaces, each containing two cast-iron ◠-shaped retorts 10 inches deep, and placed one above the other. The oil is fed into the upper retort, where it is evaporated, and the vapours pass thence into the lower retort, where their complete decomposition is effected in the presence of a greater degree of heat than is found in the upper one, the lower one being directly over the furnace. The tar is conveyed away as it is formed, and is used on the line for general purposes. The gas is conducted from the retorts to the condensers, and thence it passes through a washer and two purifiers to a meter. From the meter, where the quantity of gas produced is registered, it is led to a gasholder.

The gas having been thus produced, is only temporarily stored in this holder, its final destination being four wrought-iron cylindrical storeholders, where it is retained for use under pressure. The compressing pump has two compressing cylinders of different sizes, the larger being 7 inches, and the smaller 4 inches in diameter, both being water jacketed. These pumps are placed on the same frame with the engine, which has a 12-inch cylinder with a 12½-inch stroke, and is run at 25 revolutions per minute. The gas is drawn from the gasholder into the large cylinder, where it is compressed to four atmospheres, or 60 lb. to the square inch. It then passes into the smaller cylinder, where it is further compressed to ten atmospheres, or 150 lb. per square inch, at which pressure it is delivered into the storeholders. These holders are 18 feet long and 4 feet in diameter, and at atmospheric pressure are capable of containing 250 cubic feet of gas each, or 1000 feet in all. This, however, is increased to 10,000 feet by compression, which is the absolute

quantity stored, and which is always ready for use. From these storeholders the gas is conducted to the filling-posts, six of which are placed in the 6-foot way in the station at Hammersmith, about a carriage length apart. A coupling hose for connecting the filling-post with the carriage completes the arrangement so far as production is concerned.

The carriages are fitted with a couple of wrought-iron cylindrical receivers 6 feet long and 20 inches in diameter which are connected together by a pipe, and are fixed to the under-framing of each carriage. These receivers are filled with the gas from the filling-posts by means of the coupling hose, and it is there stored for use at a normal pressure of six atmospheres or 90 lb. per square inch, and they contain a charge sufficient for use for thirty-six hours, unless a shorter time is desired. From the receivers the gas passes through $\frac{3}{16}$-inch pipes to a regulator, by means of which a uniform pressure is always maintained at the burners. This regulator consists of a cast-iron conical vessel 12 inches in diameter and 6 inches high, the upper part of which is closed by a gas-proof membrane. To the centre of this membrane is fastened a rod with a movable joint which is placed in connection with a special valve. The gas passes from the receiver into the regulator until the tension of the membrane is sufficient to actuate the valve through the lever, the further influx of gas being thus automatically stopped. As the gas passes away to the burners for consumption, the deficiency is continually made good, and the action of the regulator is so perfect that the flame is not in the least affected by the vibrations of the carriage. A $\frac{1}{4}$-inch pipe conducts the gas to the burners, which are conveniently placed in the carriage roof, and this is the largest pipe used on the carriages. There are means for extinguishing all the lights in a carriage at the same time, and each carriage is further fitted with an arrangement for turning all the lights down simultaneously to a mere glimmer, and of turning them up again. This is very useful in cases where the train only requires to be illuminated intermittently, such as when passing through tunnels. Owing to the gas being consumed under considerable pressure, the lights, although turned low, do not become extinguished when the train moves, as they do with low-pressure gas.

Before Pintsch's system was introduced into practice, the most searching tests failed to develop any points of danger either in the manufacture, storage, or use of the gas. The experience of practical use, extending over nine years, has fully

confirmed this, and it has further shown that a permanent gas of very high illuminating power is produced, and this permanency is a very important feature when taken in connection with its storage and use under a high pressure. The fact of its being made from refuse points to economy in production, whilst the carriage appointments for its use indicate a moderate first cost there. With regard to the cost of the light, it is stated to be $\frac{1}{4}d.$ per light per hour, which compares well with either oil or ordinary gas. The proved cost of oil lamps is stated to be from $\frac{1}{2}d.$ to $\frac{3}{4}d.$ per light per hour, and that of ordinary coal gas $\frac{1}{3}d.$ per light per hour. This estimate in all cases is inclusive of interest on capital, and wear and tear. The author has occasionally travelled in carriages lighted on Pintsch's system on various railways, and has always found a bright, steady, and an efficient light.

The system has been in use in Germany and on the Continent generally for about nine years, and in England for about five years. On the Continent it is in use on sixty-three lines of railway; forty-five gasworks being in operation for supplying the gas, for no fewer than 5500 carriages. In our own country the system is in use on five lines, namely, the Great Eastern, the South-Eastern, the South-Western, the Metropolitan, and the Metropolitan District railways. There are seven gasworks in operation and two more in course of construction in connection with these lines. The number of carriages fitted and running is 700, whilst 300 more are in course of being fitted. It will thus be seen that Pintsch's system has now become well established in practice, and it is within the author's knowledge that it is giving very satisfactory results.

The success which attended the lighting of railway carriages upon Pintsch's system led to its application to buoys, in which direction it has proved highly successful. The experiments with buoys were commenced about three years since, and the author has watched the progress of their development into practice. Inasmuch as a narration of the details of these experiments would not prove of any special value, the author passes on to notice the outcome of them—the practical results. With regard to the construction, it is to be observed that the buoy itself is made the recipient for containing the compressed gas, and the lamp, which is mounted on the top, will burn for periods of six, nine, or twelve weeks, according to size, with one filling, the diameters being 7 feet, 8 feet, and 9 feet respectively. The buoys are made of wrought iron, and are of the necessary strength for resisting the internal pressure and the external blows incidental

to such objects afloat. The Corporation of the Trinity House has two spherical buoys lighted on Pintsch's system, and three more are ordered. The gas for the two buoys in use has, up to the present time, been supplied from the Great Eastern Railway gas works (Pintsch's system) at Stratford. So satisfied is the Trinity House with the results attained, that a request has been made to the Board of Trade for funds to erect a gasworks on Pintsch's system at the Trinity Wharf for the special service of illuminated buoys. One of the Trinity House buoys above referred to was placed on the East Ouze station, near the Mouse Lightship, on the 18th of April last, and remained at its station until the 28th of January last, when it was unfortunately run into and damaged by a passing vessel. The Trinity House officials report that during that period the light was burning without intermission, although it is stated by the officer in charge of the Mouse Light vessel ($1\frac{3}{4}$ miles distant) that in bad weather the buoy itself was at times hidden from view by the spray of the sea.

At Port Glasgow, the Clyde Lighthouse trustees are building a gasworks, on Pintsch's system, for the service of illuminated buoys on the Clyde. One of these buoys has been burning on the Roseneath Patch for some time past, being supplied with gas from London. A second, a bell buoy, is about to be delivered by Pintsch's Lighting Company for use on the Clyde. This company has also despatched a buoy to Port Said, for the use of the Suez Canal. This buoy the author recently had an opportunity of inspecting, and he can testify to the excellence of the light given. It will show a red light day and night for six weeks. The buoy is 7 feet in diameter, and has a capacity of 150 cubic feet. The gas will be stored at a pressure of seven atmospheres, or 105 lb. per square inch, which gives 1050 cubic feet of gas in the compressed condition. The gas being burned at the rate of $\frac{7}{10}$ths of a foot per hour, renders this supply available for six weeks. The estimated cost of gas per 24 hours consumption is $2\frac{1}{2}d.$, not a very extravagant cost it will be admitted. The process of refilling a buoy is merely a matter of a few minutes. The gas is taken to the buoy in a tender, and is passed from the reservoir or store-tank by means of a flexible tube into the buoy, where it is stored for consumption at the required pressure. By the adoption of gasworks on shore, in the vicinity of the buoys, the whole operation would be reduced to a very simple system. From the proved efficiency of these buoys, and the special advantages they offer for marking entrances to harbours, river passages,

wrecks, and the like, there can be but little, if any, doubt of their general adoption for the purposes indicated, as well as for others of a cognate character.

There are altogether five buoys on Pintsch's system in operation, and six more in course of construction. The Clyde Lighthouse trustees contemplate placing a floating lightship on this system at Garvel Point, to supersede the present lightship, which is of the old pattern, and is nearly worn out. The compressed gas will be stored in a cylindrical tank placed in the vessel, and the light will be displayed from an elevated lantern. By this arrangement the services of a resident attendant, at a salary of 80*l.* per annum, will be dispensed with.

Another important application of Pintsch's system, is that of lighting the interiors of ships, and this constitutes its most recent development. The arrangements consist of a gasworks on shore situate near the landing stage, and from which gas is supplied under pressure to cylindrical reservoirs stowed away in convenient positions on the deck of the vessel. From the reservoirs the gas is conducted to the burners, passing on its way through regulators, as in the case of railway carriages. An American river steamer, the *Narraganset*, thus lighted with 250 burners, has proved such a success, that another vessel belonging to the same owners is being similarly fitted. The only example at present in England is the City of Dublin Steam Packet Company's ship *Ulster*, on board which vessel the Post Office sorting-room is fitted with twenty-nine lights. The gas is at present supplied from London, being conveyed to Holyhead in travelling storeholders. The lights are reported to burn with perfect steadiness even in a gale, and so satisfactory are the results that the Post Office officials are asking that the other three ships belonging to the company may be similarly illuminated.

The latest proposition in connection with Pintsch's system, and which is now in course of development, is to light isolated railway stations with the compressed gas. In such cases the gas will be conveyed in a compressed condition in storeholders, carried on ordinary railway trucks. On arriving at the station thus lighted, the contents of the storeholder will be transferred, by means of a hose and filling-pipe, to a small bell gasholder of the ordinary type. From the holder the gas will be conducted through service pipes to the lamps. A proposition is now under consideration by the South-Western Railway officials for applying this system to various stations on their line. The idea appears to be one which is well worthy of consideration,

and if the practice proves successful, there is no reason why the principle should not be extended to other buildings in the country which are cut off from a supply of ordinary gas.

Such are the various systems for lighting by means of compressed gas which have come under the author's notice. It might be desirable to institute some comparisons between them as regards their relative cost, and also on points of practice. As regards cost, this would be both impossible and unfair. Impossible, inasmuch as in Sugg's system the cost of gas has not yet been definitely arrived at in practice, and unfair because in Bower's system the stated cost, being based upon experiment only, is as likely to prove erroneous in favour of, as against, Mr. Bower. As regards points of practice, little or nothing can be said by way of comparison, as the first four systems described—that is, Sugg and Clark's enriched, Sugg's cannel, Sugg's improved enriched, and Bower's—have neither of them advanced beyond the experimental stage. As between Sugg and Bower, however, the author may observe that he considers the system of carburetting the gas at a fixed station far preferable, on the score of safety, to conducting that operation in the carriages of a train travelling at express speed, and within a few inches of the passengers. As regards Pintsch's system, its extensive adoption points to its practical value, and indicates that it possesses merits which, although they may exist in the other systems, have not yet been sufficiently developed to win for them a similar recognition. There can be no question of the value and usefulness of Pintsch's system in connection with its existing applications, nor can it be fairly doubted that it has a wide future before it.

In conclusion, the author would observe that his paper possesses some defects, of which he is fully conscious. It was, however, undertaken at short notice, in order to fill a gap which was unfortunately created by the Council having been disappointed in a paper promised for the present meeting, and it has been prepared during such intervals as could be snatched from a busy life. He has, however, endeavoured to place clearly before the Members the leading particulars respecting the progress of railway carriage lighting, and he trusts that any shortcomings on his part will be more than compensated for in the discussion which will ensue upon a matter in which reform is so greatly needed and so slowly effected.

DISCUSSION.

Mr. Duckham said that between 1868 and 1870 Mr. Henry Duckham lit tramcars and railway carriages by compressed gas; he tried the system invented by him on the North Metropolitan Tramway and the Midland Railway. He (the speaker) believed that the result was perfectly satisfactory; and as far as he remembered, except only the enrichment of the gas, the apparatus which was then used was precisely the same as that which had been adopted by the persons who had been referred to in the paper. Fortune smiled on Mr. Duckham in another direction, and he did not follow up his invention as it deserved. If he had done so, probably his system of lighting railway carriages would have been brought into extensive use some years previously. He was sure that the Members of the Society would like to give honour to whom honour was due.

Mr. Eaton said he thought it would be found that about twenty years ago Mr. Bower suggested the lighting of carriages by compressed oil gas. The idea was, however, too much in advance of the age, and there was not much chance of getting any company to adopt it at that time, although Mr. Bower's experiments were perfectly successful. Gas was then much more expensive than it is now, especially that made from oil. The condition by which Mr. Bower was tied by the Great Northern Railway Company in his recent experiments, was that he was to use the ordinary gas which would be available at every railway station and enrich it, and this he had succeeded in doing. There was a difficulty in getting a sufficient amount of gas of high illuminating power other than oil gas into so small a reservoir as would be laid on each carriage. No comparison could be made between Mr. Bower's enriched gas and Pintsch's system, the conditions not being equal, as the latter only used a gas made from oil which was very expensive, and required special apparatus for its manufacture.

Mr. Price Williams said that at a time when they heard so much about the new electric light, it was very encouraging to find so much scope still left for the employment of gas, to which, for lighting purposes, they had so long been accustomed. As an old Great Northern man, he had felt a great interest in the practical solution of the problem of providing an adequate supply of artificial light for the carriages on that railway, and from what he had already seen of Mr. Pintsch's system, now in use on the Metropolitan, he was encouraged in the belief that complete success would result from its adoption on the Great

Northern Railway, and hoped that the example set by the Great Northern and Metropolitan Railway Companies would be speedily followed by some other of our principal railways, which it was unnecessary to particularise, where the present system of carriage lighting was simply disgraceful, there being just sufficient light to make darkness visible, and to render reading impossible. For his own part, he had no fear that the electric light would do more than stimulate gas manufacturers to show what a splendid illuminator it was capable of being rendered.

As an illustration of a new and important application of gas for lighting purposes, he might mention that his old friend and schoolfellow, Mr. Douglass, the Chief Engineer to the Trinity Board, had recently been explaining to him a new application of Mr. Pintsch's process of lighting to the illumination of buoys, by means of which, in Mr. Douglass's opinion, the dangers arising from shipwreck and collisions at sea, all along our rock-bound coasts, would be very largely diminished. It was well known that the general introduction of steam navigation had largely increased the number and dangerous character of these collisions at sea, and it was quite reassuring to hear Mr. Douglass express his firm belief that we should shortly, through the instrumentality of a continuous series of illuminated buoys all along the most dangerous parts of our coast, have two distinct roadways afforded for our sea traffic; the line of illuminated buoys enabling the up and down sea traffic to be separated, just after the fashion adopted in working the traffic on our railways. He further understood Mr. Douglass to say that this brilliant idea had originated with one of the officers of the Trinity Board. There could be no doubt, he thought, that if this method of buoy illumination was carried out systematically all along our coasts, the result would be such as to render the dangers of navigation very much less, and make such terrible and fatal collisions as had so frequently occurred of late years in connection with our steam navigation impossible in the future. The method alluded to in the paper for providing a gas supply for our small railway stations by means of movable tanks containing the compressed gas, struck him as being exceedingly ingenious and practicable, and as supplying a great and acknowledged want at the multiplicity of small stations throughout the kingdom. What had struck him perhaps most of all in this valuable and important paper of Mr. Nursey's, was the enormous field for the further utilisation of gas, which, according to the author's showing, the inventive genius of those who were specially devoted to this branch of engineering was so rapidly

developing, and altogether he considered the new and various applications for the employment of gas, indicated in the paper, were such as ought to inspire hope into the most faint-hearted gas shareholder.

Mr. WALMISLEY said that they must all agree that Mr Nursey had put the subject before them in a very able, clear, and concise manner. A friend of his was present, who, in the early days of this subject had made some experiments connected with compressed gas. And he desired to introduce his friend Mr. W. Barns Kinsey, who was there as a visitor, and to ask the President to call upon Mr. Kinsey to explain the nature of his experiments and the mode of conducting them, as he thought the discussion would be aided by the addition of such results.

Mr. NURSEY said that it had been his intention to do what Mr. Walmisley had proposed. In 1868 Mr. Kinsey had lighted the carriages on the Great Northern system.

Mr. KINSEY said that matters had very much improved since he had had to do with gas lighting, and patented his gas carburettor in 1868. He used a plain cylindrical vessel with a diaphragm of felt. The felt was kept saturated with benzole by means of wicks; and a double coil upon the surface of the felt conducted the gas several times about the surface. The felt charged the gas with the carburetting material, which was a compound of benzole. Dr. Letheby was the pioneer in this matter, in fact he (Mr. Kinsey) was a humble disciple of his. Dr. Letheby found that gas could take up eight grains of the carburetting material per cubic foot. He (Mr. Kinsey) found out that it would take up eleven grains, without the material being condensed, at the ordinary temperature. He passed the gas through a coil which was covered with ice in order to test it before applying it to railway carriages. The hydro-carbon had a specific gravity of 0·860 at a temperature of 40°. The mixture which would work best was $\frac{2}{5}$ benzole and $\frac{3}{5}$ toluol $C14 \cdot H8$. The boiling point was 200° Fahr., and it evaporated at 260° Fahr. An inflammable vapour was given off at 63° Fahr. A mixture which would give a constant quantity of eight grains per cubic foot and raise the illuminating power 60 per cent. might be obtained with a colourless naphtha of from 0·830 to 0·860 specific gravity, which begins to distil not higher than 230°, yielding on distillation 70 per cent. from 266° and 20 per cent. from 302°. Four trains were fitted up with the apparatus on the Great Northern Railway. The ordinary light when he came to it was five candle-power to each burner, and the consumption was 4 feet an hour

with a pressure of five-tenths. The carburetted gas with the same pressure gave twelve candles at $2\frac{1}{4}$ feet per hour. The pressure was ultimately reduced to two-tenths, and the light was reduced to a minimum of seven and one-eighth candles with 2 feet of gas an hour. This enabled the Great Northern Company to carry out what they wished to do. The gas in the holders lasted only three and a half hours, and that was not sufficient to give them two trips from Hatfield to Victoria without having to fill up, and the filling up was inconvenient inasmuch as they had not time to do it. Mr. Oakley therefore asked him to bring his carburettor forward, and gave him an opportunity of making experiments. He was then enabled to give 2 feet of gas per hour with a minimum light of seven and one-eighth candles, making the gas last eight hours instead of three hours. It was found that the gas would not inflame at the ordinary temperature at a greater distance than 4 inches from the surface of the fluid. At 200° temperature it could not be inflamed at the end of a tube 3 feet long. As regarded the quantity and the cost, they found that it was 6*d.* per thousand feet. 3*s.* 6*d.* for the thousand feet of gas and 6*d.* for the carburetting made 4*s.* per thousand feet, which was thought to be very satisfactory, especially with the increase of illuminating power. The increased price of the carburetting material prevented this method from being followed up. When he first took up the matter he could obtain the carburetting material at 2*s.* 4*d.* a gallon. It afterwards rose to 14*s.* 6*d.* a gallon owing to its demand for aniline dyes.

Mr. Anthony Bower asked, as the eldest son of Mr. Bower, to be allowed to state that their system of carburation had been specially tested at King's Cross for 125 hours consecutively, and the result had been that 645 cubic feet of gas and $9\frac{1}{2}$ pints of naphtha, costing somewhat less than 1*s.* per gallon, had been consumed. The 645 feet lasted over 125 hours for each of four lights, which was equivalent to 500 hours for one light. With ordinary coal gas at 3*s.* 6*d.* per thousand cubic feet, this would enable a light consuming $1\frac{1}{4}$ cubic foot per hour to be burning for ten hours for less than a penny, and the light was abundantly sufficient, as had been certified to by Mr. Oakley, the General Manager of the Great Northern Railway. The difficulty which they had found in carburation had been the difference in temperature at different times of the year; and as in this climate the temperature changed extremely suddenly, the gas of one time was more carburetted than at another, and it was difficult to maintain a uniform light within the carriages.

This had been overcome by isolating the vessel containing the naphtha entirely from external temperature, together with a special form of carburator, and this had prevented variation in the lights. As common coal gas, together with the carburetting liquid used, could be obtained anywhere, the system offered many advantages, not the least being that of very much reduced cost over any other which had hitherto been introduced, so far as he knew.

Mr. James L. Chapman said that he had that morning gone over the Pintsch gasworks of the Metropolitan Railway Company by permission of Mr. Tomlinson, and he ascertained that the cost of putting the gas into the holder, without the wear and tear, or the original cost of the machinery, was 13*s.* per thousand feet. They burned seven-tenths of a foot of gas at each burner per hour, as compared with 4 feet of ordinary coal gas. There were two burners in the first-class carriages, and one in the second. A great saving was secured by the company, from the fact of not having to stop the carriages for filling. They were filled in the morning and they were done with for the day. Under the old coal-gas system, the carriages had to be filled more frequently, and a man had to be kept for the purpose, and the operation of filling used to be very unpleasant to the passengers. He believed that $\frac{3}{4}$-inch lead pipes were used between the compressing engine and the reservoirs. It appeared that Pintsch's system was a great deal cheaper than the ordinary system of using coal gas. Looking at the matter in the light in which the last speaker, Mr. Bower, had placed it, he though that the system of carburetting ordinary coal gas, if it could be done satisfactorily, would be much the cheaper.

Mr. Spice said that it had struck him that in this matter of gas lighting, history had repeated itself. He was just old enough to remember a time, when there was a company in London whose business it was to manufacture gas and put it into bottles, and send it down into the country. He had lived in a town which was partially lighted in that way. He referred to the town of Braintree, in Essex. After all that they had learnt and all that they had forgotten, it was rather refreshing to find engineers going back to the process of manufacturing gas, and compressing it, and sending it where it was wanted. With regard to his friend Mr. Price William's remarks, he was charmed with the idea of having streets on the ocean highway, as in our towns and cities, and having them lighted up with gas buoys, charged, or filled, at convenient places, and containing enough gas to last for weeks or months. It was a

very bright prospect for Englishmen to have the dangers of ocean travelling diminished by means of this modern appliance. As to the competition of electricity with gas, he believed, even if electricians did as much for electric lighting as gas men had done for gas, that still the prosperity of the gas interest would rise on the back of the interest of electricity. He was not a believer in the doctrine of finality, but he did believe that the judicious and earnest efforts which had been set forth in the paper, would result in greater things than they had yet known, and that the world at large would be the better for the discoveries which had been and were being made, and for the application of that knowledge which they were all concerned in increasing. Mr. Douglass, one of the engineers of the Trinity Board, had invented a new burner, and would have been present to take part in this discussion, but he had been detained by domestic affliction. The burner had been invented for the new Eddystone Lighthouse, which he designed, and was now engaged in erecting.

Mr. Schönheyder said that it seemed to him that there were several defects in the Sugg pressure governor which was described by Mr. Nursey. First of all, the parts were not balanced. It seemed that, in consequence of the iron plate on the top of diaphragm, together with the little valve, and the lever and spindle, not being balanced, a series of oscillations in the railway carriages would produce a motion of the valve, and by that means vary the pressure. Further, the use of the screw seemed to be very objectionable, as introducing the element of friction, so that considerable variation of the pressure of gas would take place before the valve could be changed. There was the friction of the screw in the nut, and also the friction of the screw on the valve. The other pressure-reducing valve appeared to be likely to work with greater exactness. All the parts were balanced so that the railway carriage might move up and down or sideways without affecting the pressure of the gas. He understood from the paper that the compressing engine used in Pintsch's system made only twenty-five revolutions per minute. That was an unusually slow movement for a compressing pump for gas; it ought to work much more quickly, with great advantage in first cost compared to work done, and a great diminution in leakage.

Mr. Rickman said that if gas of some kind was to be used for railway carriages, one material question for railway directors and officers to consider was the question of cost. In a statement which had been made, the price of coal gas was put

at 3s. 6d. per 1000 cubic feet, and it was said that an additional expenditure of 6d. a thousand for carburetting would produce a very highly illuminating gas. To this expenditure must be added the cost of compressing, and the number of compressing stations must be taken into account. It had been stated that evening, that Pintsch's gas, compressed, cost 13s. a 1000 cubic feet. It was therefore really a question of how much they were going to burn per hour. Of course they were not met to discuss commercial questions; but when engineering questions were being considered, the question of cost was a very material one in a practical discussion, and Mr. Rickman had seen it publicly stated in a newspaper that carburetted and compressed coal gas cost 6s. 8d. per 1000 cubic feet.

Mr. Kinsey said that he ought to have stated with regard to the carburetted gas of which he had spoken that it was only compressed in the ordinary way, the gasholder being raised by means of a winch, and then allowed to fall by its own weight; 3s. 6d. a thousand was practically the cost of the gas.

Mr. Jabez Church said that he had noticed in Pintsch's lamps on the Metropolitan District Railway that there was a better light when the train stopped than when it was moving. He did not know whether this variation was due to a defective arrangement in the admission of air into the lamp. In these days, when everybody travels, it is most desirable that railway carriages should be properly lighted, and this applies more especially to the underground railway. If under Pintsch's system a little larger light were given, passengers would be able to see better, for if 1 foot of gas per hour is not sufficient 1½ foot should be supplied. On the Metropolitan and District Railway, whatever the defects of the ordinary gas lamp now in use might be, they certainly gave a remarkably good light, and one by which travellers could see to read as easily as they could in a well-lighted room.

Mr. William Adams said that he had had some little experience in lighting railway carriages with gas. On the North London Railway, with which he had been connected, they took up Newall's system about the year 1862. The gas was carried in a holder in the brake van and a pipe was carried along the roofs of the carriages. Means was taken in Newall's system to compress the gas in order to give it the proper pressure. A vessel, which might be called an eggend boiler, was filled with water. The water was run out and a vacuum was formed above the water. The gas valve being opened, of course the vessel was filled with gas. The water was then admitted again and

it compressed the gas. The water valve remained open and the water rose as the gas was used out of the holder. This system was objectionable in some respects, because a great deal of air came in with the water and vitiated the lighting power of the gas. Newall's system had been abandoned, and the carriages of the North London Railway are now lighted with gas direct from the gasholder, the gas companies providing sufficient pressure for all practical purposes and using very large pipes, which of course assisted to avoid friction by loss of pressure. While he was connected with the company, they were very anxious to improve their lighting, and they tried various systems of carburetting. Messrs. Carless and Blagden, of Stratford, two very able chemists, who worked at it for several months, tried a process of carburetting the gas by means of a hydro-carbon, which they called carburne. This very much improved the light, but after several months of careful attention and experiment, those gentlemen were unable to lay any practical suggestion before the company, as their method was too costly. Mr. Kinsey's experience in connection with the rise in the price of the material seemed quite to correspond with that of the North London Railway Company. He (Mr. Adams) had more recently had to do with Pintsch's system on the Great Eastern and the South-Western. This system seemed to him to be the most promising of any which he had seen. The gas gave a steady light, and there seemed to be very little condensation. He had never noticed that the light improved when the train was standing still. He failed to see any difference in the light in that respect whether the train was running or standing. Upon one occasion the gas had gone out, but it was found that the holder was empty in consequence of the severe weather having prevented the train from going into the siding at Clapham to be filled; since then a small oil lamp had been prepared for the purpose of being put into the roof lamp glass, in case of a failure in the gas supply. It would be very interesting to the meeting if some one could tell them of some experience in which carburetted coal gas had been used successfully for the lighting of carriages with good commercial results.

Mr. Nursey said that the few points which had been raised having been answered, left him nothing to reply to. There was no question that for many years attempts had been made to improve ordinary gas by carburetting it, and it seemed that the only two inventors who had succeeded so far were Mr. Sugg and Mr. Bower. Mr. Bower had shown that the cost of

his gas, so far as he had gone, was less than that of Mr. Pintsch's gas, but there were other considerations which ought to be taken into account. These considerations had been placed before the meeting by Mr. Rickman. In making a comparison between Sugg's system and Bower's system, he (Mr. Nursey) gave preference to the method of carburetting in stations and at fixed points, before the method of carburetting in carriages as adopted by Mr. Bower. Perhaps, in fairness, he ought to modify that opinion by referring to the fact that, not knowing the exact details of Bower's system, the patent not having yet been published, he ought not to form an absolute opinion. At the same time it still appeared to him that in any case there must be some danger arising from the use of such light and highly inflammable gases, and that they had far better be dealt with at a station than in the travelling carriage. He was sorry that neither Mr. Sugg nor his representative was present to answer Mr. Schönheyder's question as to the valves not being balanced. He (Mr. Nursey) could only judge from a few runs he had made in carriages lighted by Sugg's method where there was no oscillation, and the lights burned steadily. The same remarks applied to Mr. Bower's system. In fact all three systems were excellent examples of railway carriage lighting. He had not noticed the diminution to which Mr. Church had referred in Pintsch's light, either on the Metropolitan or any other line. He had made a very quick run from Salisbury some time ago, and there were some very quick stoppages, but he did not notice any variation in the light. He had, however, frequently noticed that oil lamps went down during running and brightened up a little in the stations. The reverse occurred in Mr. Bower's system. While the trains were running the light was brighter than during the stoppage at stations. He could not say to what it was attributable. There was no doubt that if all the requirements which he had stated in his paper could be met, there would be a very wide field open for ordinary gas, carburetted and enriched. At present, however, there was no question that the oil gas took the lead.

The President, in closing the meeting, said that there were one or two questions which he should have liked to ask in order to make the paper more complete. It was not quite clear to him that the author had stated the cost of oil versus Pintsch's system. Then he should have asked a question as to the illuminating power. He agreed with Mr. Church, and he should himself like to see a better light in railway carriages. He was afraid that railway companies were going to work so

economically, that the passengers would be as badly off as they were before, or worse. It appeared to him that the expense of having cylinders on the tops of all the carriages would be very great. Why should not a special tank be used for the whole train? He was sure that railway companies would be going in the right direction by giving the public a constant light both day and night.

In answer to a question, Mr. Rickman said that he had been told by the gentlemen who had the gas buoys under their charge, that with the assistance of the dioptric lens, the light was visible for four miles on an ordinary night, and for six miles on a clear night.

May 2nd, 1881.

CHARLES HORSLEY, PRESIDENT, IN THE CHAIR.

ON FLOATING DOCKS.—THE DEPOSITING DOCK AND THE DOUBLE-POWER DOCK.

By JOHN STANDFIELD, M.I.C.E.

The great difficulty experienced in the provision of dry dock accommodation, even where urgently required, has always been the immense amount of the first outlay which has to be incurred. Dry docks have generally been constructed by engineers accustomed to build works in stone and concrete; their enormous cost has been regarded as unavoidable, and therefore their provision has been undertaken only where there has been much shipping to be accommodated. There are, however, many ports where dry docks would be profitable if they could be provided at half the cost of a stone or concrete dock. Messrs. Clark and Standfield have consequently given the subject of docking accommodation special attention, and, having had the advantage of large experience, have designed docks which can be built at a much lower cost than has been hitherto considered possible.

The positions and circumstances under which dry docks are required are very variable; the vessels to be docked may be large and heavy, or small; the docks may have to be placed either in exposed or in sheltered positions; they may be required in a strong current or in quiet water; in places where there is a great rise and fall of tide, or in a harbour where there is nearly a constant water level; the number of vessels to be docked may be very great, or provision for a single vessel at a time may be sufficient. All these opposite requirements are fulfilled either by the depositing dock or by the double-power dock.

There are various forms of floating docks now in use. One of the largest and best known is the Bermuda Dock, constructed in 1869; this has a flat bottom and curved sides, so that the outline of the section is roughly ship shape. Its length is 381 feet over all, and 330 feet inside; its breadth over all is 124 feet, and 84 feet inside. It is divided longitudinally into

eight, and transversely into three watertight compartments on each side of the keel. It is provided with two caissons, and can take vessels drawing up to about 26 feet of water.

Another well known floating dock is that at St. Thomas. This dock is formed of six main pontoons extending the whole breadth of the dock. It is 300 feet long, 110 feet broad over all, and 72 feet broad inside. Each pontoon is divided into three watertight compartments. Each side of the dock is formed of a pair of girders, 35 feet deep, resting upon the outer ends of the pontoons. Between each pair of girders are placed six floats, about 50 feet long, by $11\frac{1}{4}$ feet broad, and 5 feet deep. The object of these floats is to counteract the tendency to cant, and also to prevent the dock from sinking too far. They are worked in four groups of three each, by two special high-pressure engines. Each float can be raised or lowered by three vertical screw shafts worked by gearing. This dock will take vessels drawing up to 24 feet of water; it was constructed in 1866, but soon after its completion a breakdown unfortunately occurred, and it went to the bottom, where it remained for a considerable time; it is however again at work.

The sectional floating dock is best known in the United States. It is constructed of timber, and is formed of similar sections. When a vessel has to be docked, the number of sections necessary to make up, by their breadth, the length of the vessel, is joined together by connecting beams, so arranged that after the vessel is lifted, and the beams keyed up, the several sections become as one structure. These beams can be placed at any distance apart, from 6 inches to 6 feet. The shafting which conveys the power of the engines from one section to another runs into a hollow sliding shaft, which may be slid in or out. These docks are provided with "bedways" for transferring the vessel to the shore by means of a cradle worked by hydraulic power. Such an operation is full of risk, and we are informed has caused many accidents.

Another American pattern of floating dock is the balance dock. This is a timber dock of ordinary form, provided with gates, and divided into watertight compartments.

The floating dock most in favour on the continent is an iron dock of the usual shape, constructed in similar sections, which are connected together by means of large girders forming the sides to which they are riveted.

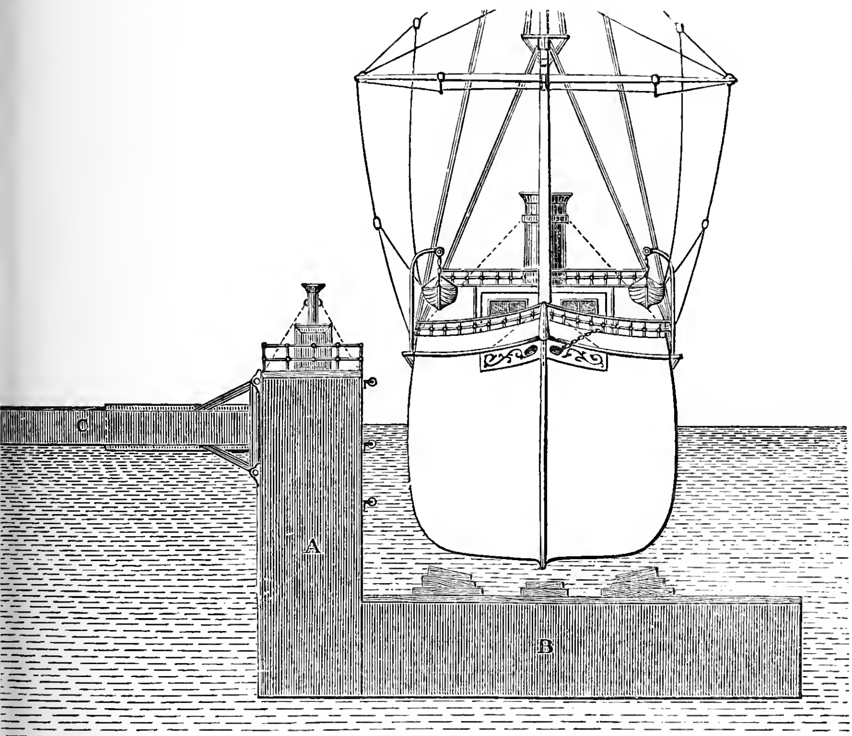
It would perhaps not be proper now to examine the failings and disadvantages of these various forms of floating docks, and the author therefore proceeds to the description of the two new forms already mentioned, which essentially differ from all floating

docks hitherto constructed, and which, it will be seen, have considerable advantages over them all.

Both the depositing dock and the double-power dock are very simple in their construction, which is everywhere rectangular and uniform, avoiding all curved and special work; they require no floats, gates, or caissons, and they are provided with so many watertight compartments that they cannot sink even if all their valves be purposely left open.

The depositing dock has the very great advantage that, by means of its staging, it can accommodate any number of vessels

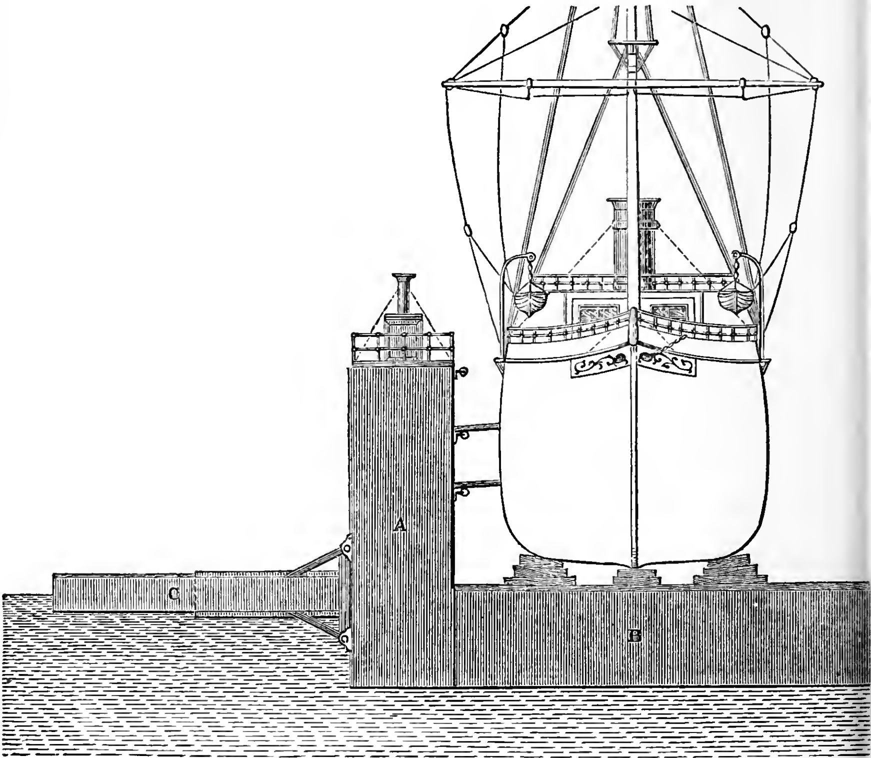
Fig. 1.



at the same time, as shown in the general view (p. 89); it is particularly suited for use in wet docks, and in sheltered harbours where there is a pretty constant water level. Its unusual form and the manner of its working will be easily seen by referring to the figures. The end elevations, Figs. 1 and 2, show it to

be an L-shaped dock, that is, having only one side; the broad, shallow pontoon attached on the left of the vertical side of the dock is called the outrigger; its function is to keep the dock horizontal while being lowered or raised. The stability given

Fig. 2.



by the outrigger is quite equal to that of a dock with two sides. Fig. 5 shows a plan of the dock, by which it will be seen that the bottom consists of a series of parallel fingers or pontoons, firmly connected to the vertical side, but quite free at the outer ends. These pontoons are divided into several watertight compartments by means of internal bulkheads; some of these compartments are permanently closed, so that it is impossible to sink the dock. Each compartment has independent pipe connection with the pumps, which are situated in wells close to the bottom of the vertical side, and which are worked by two

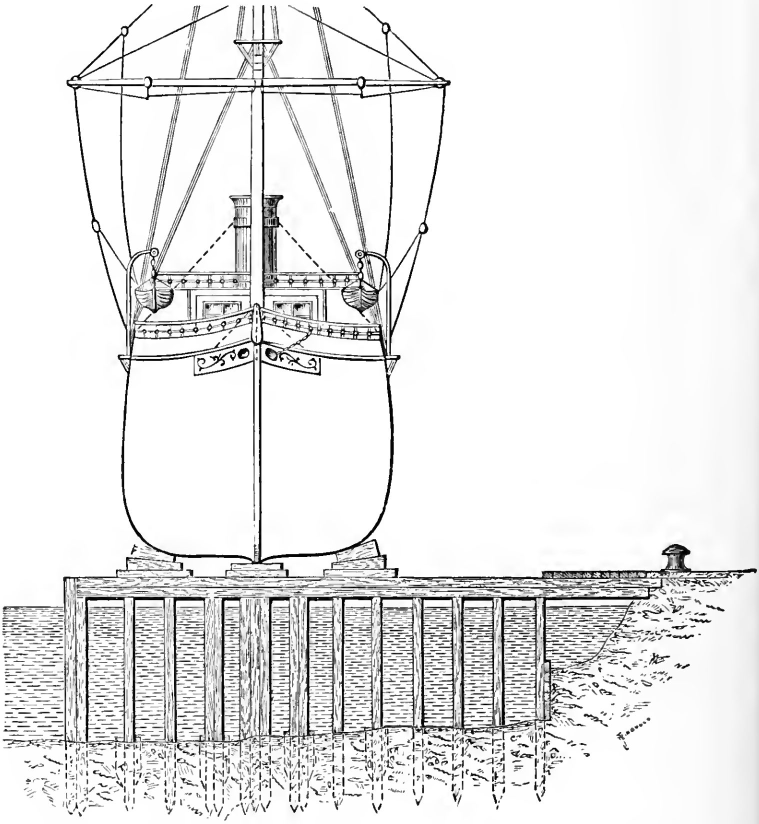
or more semi-portable engines placed on an engine deck in the vertical side. The side is also divided into separate watertight compartments. The pipes are divided into groups, controlled by valves, which are worked by one man on the upper deck. The outrigger is divided into watertight compartments, and is ballasted so as always to float at half its depth. It communicates with the upper deck by means of self-adjusting ladders, and with the pontoons by means of gangways passing through the side of the dock; it forms a convenient store for tools and materials.

When the dock has been lowered by admitting water in the usual manner, the vessel is brought over the pontoons, and readily centred by means of movable shores (not shown in the engravings) which are easily controlled from the upper deck; sufficient water is then pumped out to cause the vessel to take a bearing on the keel blocks on the pontoons; the sliding bilge carriages are then drawn in by chains, also worked from the upper deck, and the vessel is thus secured. Pumping is then continued until the vessel is raised clear of the water, as shown in Fig. 2. These sliding bilge carriages are very broad, and form an unusually firm cradle, which cannot be displaced even when struck by a heavy sea. The lifting power of the dock is obtained from the pontoons only, the buoyancy of the vertical side sustaining merely its own weight.

The special feature of this dock, from which it has been named, is seen in the next operation, viz. that of depositing the vessel on the staging. Fig. 3 shows an end elevation or section, and Fig. 4 a plan of the staging, which is formed of parallel rows of vertical piles of iron or timber, capped by horizontal timbers. These rows of piers, which are erected at right angles to the shore line, are 4 or 5 feet broad, and from 12 to 15 feet apart. To deposit the vessel, the dock is brought up to the staging, and its pontoons passed between the piers; the keel of the vessel passes clear above the middle line blocks on the staging the outer blocks being temporarily turned down. As soon as the vessel has been brought over the keel blocks on the staging the dock is lowered, the vessel takes her bearing, the bilge blocks are immediately drawn in in the dry, and the dock is withdrawn, ready to raise or lower another vessel. A few feet variation in the level of the water can always be accommodated by the use of more or less blocking, and vessels of any breadth, however great, can be raised and deposited with the utmost facility. The operation of lowering a vessel from the staging into the water is necessarily the exact reverse of that of raising, which has been fully described.

It will be seen that the depositing dock is specially suitable for large commercial ports where many vessels have to be docked, as one dock can serve any number of vessels, the number of vessels that can be accommodated is, in fact, limited only by the length of staging provided. The dock is very economical in its working, and requires much less pumping to

Fig. 3.



be done than an ordinary stone dock. When a vessel is on the staging it is fully exposed to light and air, and is in an exceptionally favourable position for being painted or repaired.

The depositing dock is constructed in two equal portions, each furnished with engines, pumps, &c., complete, so that each portion can be used as an independent dock for smaller vessels, each portion can also at any time be docked on the other

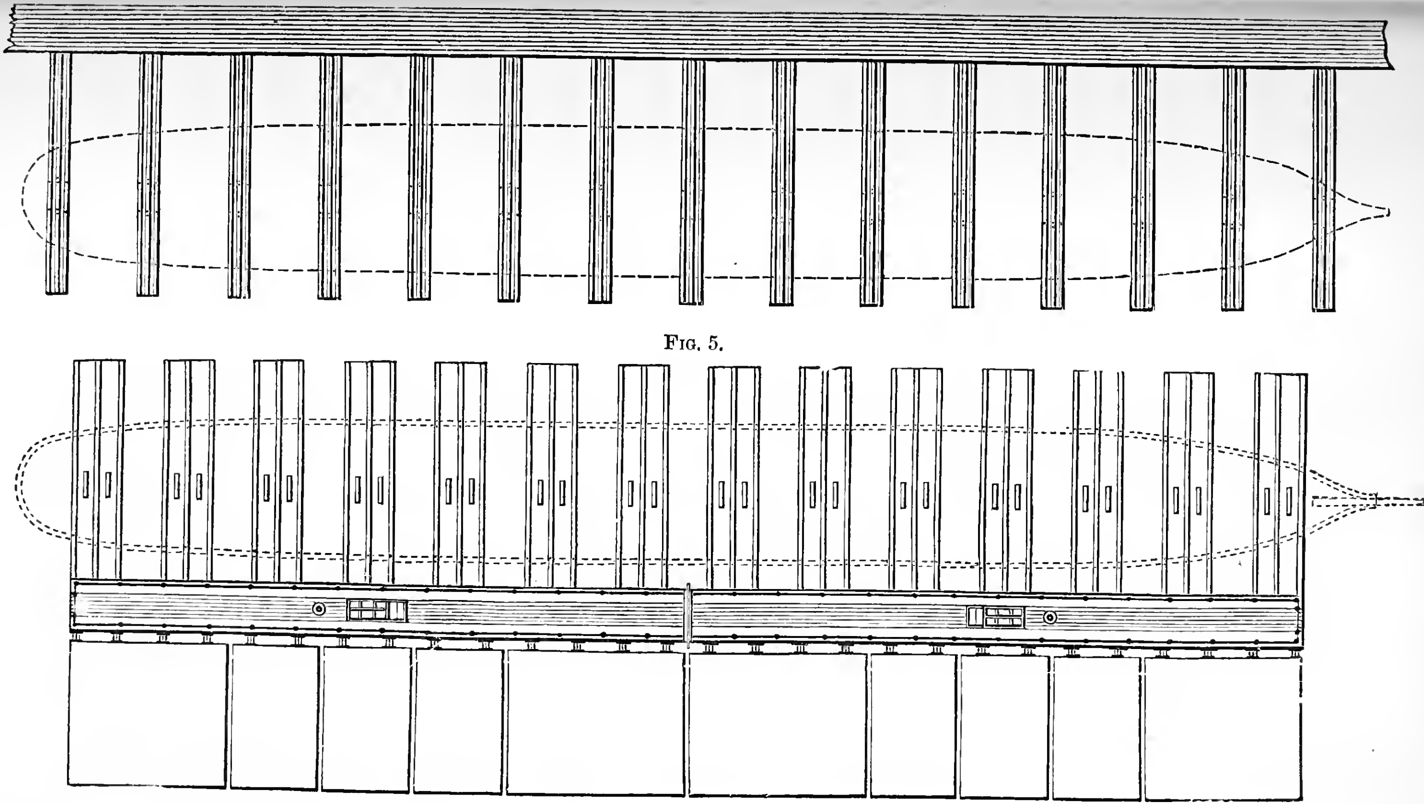


Fig. 5.

portion without any heeling over, so that all parts are readily accessible for cleaning and painting, thus enabling the dock to be kept in the most thorough preservation.

The staging can be erected in comparatively shallow water, as it is not necessary to have a much greater depth than the draught of the dock with the vessel on it, say from 10 to 15 feet; but where the vessels are raised or lowered, which can always be done at the same spot, there must be a depth equal to the depth of the pontoons added to the draught of the vessel. Vessels can, with advantage, be built on the staging, and lowered into the water at a very small cost, without any rolling or sliding motion, and without running the risk of straining incurred by launching.

The time occupied in docking a vessel of any size need not exceed two hours, and in lowering, half-an-hour; a vessel can, of course, be raised, sighted, and refloated in less than two hours.

In 1876, Messrs. Clark and Standfield constructed, for the Russian Government, a large depositing dock, which did them good service during the war by docking all the Russian vessels in the Black Sea, including the great circular ironclads, and it has been in constant use ever since; last year the same firm extended its lifting power from 4400 to 6000 tons; the Russian Admiralty, the captain of the dock, and all connected with it speak with the highest praise of the facility of its working. It is the only dock in the world which can accommodate the 'Popoffka,' and the 'Livadia,' which last, it will be remembered, is 152 feet in breadth. Messrs. Clark and Standfield have recently contracted for a depositing dock for Barrow, to dock vessels up to about 3200 tons displacement, and also for another dock for the Russian Government, to dock vessels up to about 8000 tons displacement.

The following are among the chief advantages of the depositing system:—

1. One dock can accommodate any number of vessels by means of staging, which can be erected along the waste shores of a river or wet dock.

2. The dock can take a vessel of any size, and of a breadth too great to enter any other fixed or floating dock.

3. Each half of the dock is complete in itself; and can be used as an independent dock for smaller vessels, and for docking the other half.

4. Each additional length of staging provides the accommodation of an additional graving dock at a very small cost.

5. Vessels can be built on an even keel on the staging, and can be lowered into the water without any strain, avoiding

NERAL VIEW OF A NAVAL ESTABLISHMENT PROVIDED WITH CLARK AND STANDFIELD'S PATENT GRIDIRON STAGE AND DEPOSITING DOCK.

the risk and cost of launching, and saving the space required for a slip.

6. The dock, either with or without a vessel, can be towed from place to place for the purpose of docking and depositing vessels at different points.

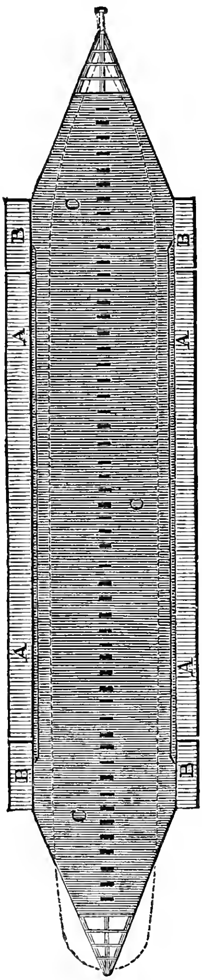


Fig. 6.

7. The dock cannot sink, even if all its valves be left open by accident or intention.

8. The dock can at any time be enlarged as occasion may require, at the same rate per ton as its original cost.

9. With sufficient staging, one of these docks can accommodate a very great number of vessels daily, and can therefore earn a very much larger dividend than any other form of dry dock.

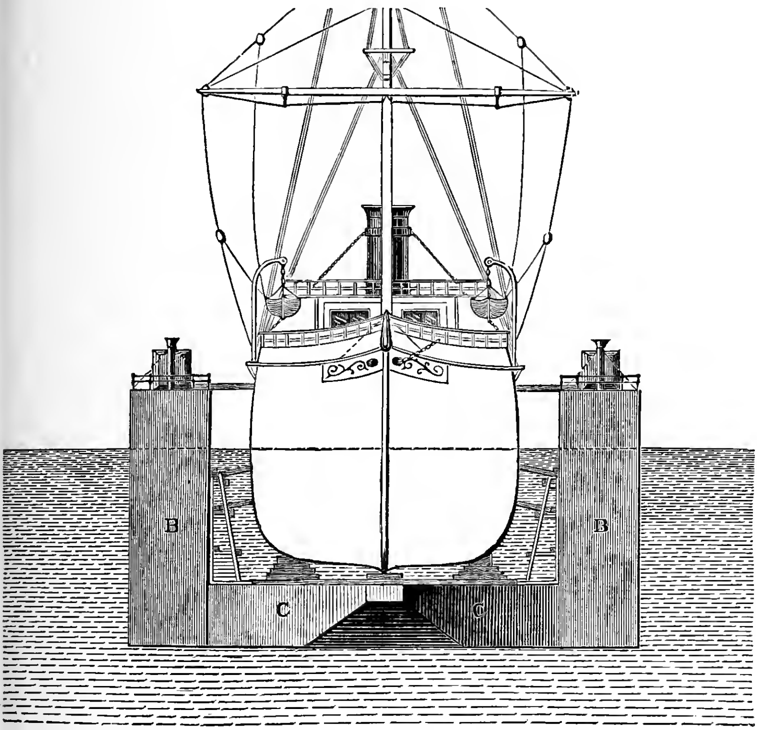
The double-power dock has two spe cial features of very great importance. The first is that of utilising the buoyancy of its sides as well as that of the bottom; it therefore requires a much less weight of iron for doing the same work as an ordinary floating dock, and is consequently much cheaper.

The second feature is that it is able easily to dock itself, so that every part can be readily got at for cleaning and painting, and the life of the dock thus indefinitely prolonged.

In an ordinary floating dock the sides add to the weight to be lifted, and, as far as the power of the dock is concerned, they represent useless cost. All the work of lifting has to be done by the bottom or pontoon, which must therefore possess sufficient buoyancy to lift the two sides of the dock as well as the vessel. If, now, means could be taken to avoid the necessity of lifting the weight of the two sides, it is evident that a great economy could be effected, either by employing a smaller pontoon, or by lifting a heavier vessel for any given weight of ironwork in the dock; and further, if means could be taken of making the buoyancy of the two sides *assist* the pontoon, a still greater economy could be effected in either of these

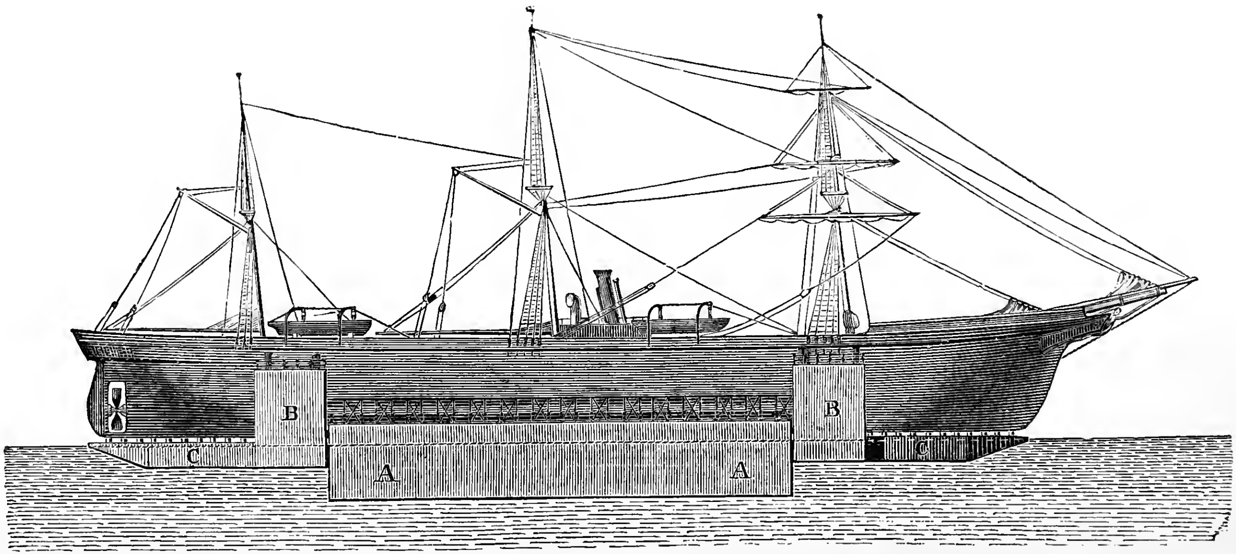
directions. It is just this economy that is effected by the double-power dock. Fig. 6 is a plan of the dock, and Fig. 8 a side elevation showing a heavy vessel docked. The sides marked A are enabled to slide up and down between fixed corners B; C is the pontoon. When the sides are secured in the usual position, the appearance of the dock is like that of an

FIG. 7.



ordinary floating dock, and the dock is lowered in the customary manner ready to receive a vessel. When the vessel has been secured by shores or sliding bilge carriages, as shown in Fig. 7, it is raised as far as possible by pumping out the pontoon, the sides are then lowered, one at a time, by allowing water to enter them, and are secured in their new low position, in which they have at least 5 feet freeboard. They are then pumped out, thus adding their lifting power to that of the pontoon. The vessel is thereby raised as shown in Fig. 8, the buoyancy of every part of the dock having assisted in the lifting except the four fixed corners. These corners, which have a freeboard of 5 feet, are divided into watertight com-

Fig 8.

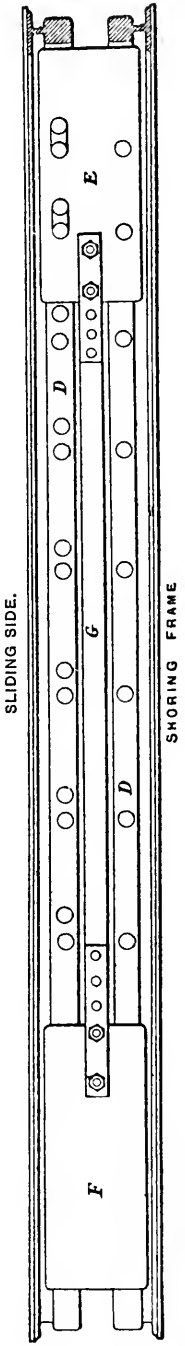


partments. The ends of the pontoon are pointed, so that the lifting power may be chiefly exerted under the heaviest part of the vessel. On the pontoon are built strong upright frames, every 6 feet apart; these are used for supporting the shores to the vessel, and also as guides to the sliding sides. The sliding arrangement is shown in detail in Figs. 9 and 10. One of the vertical bars, D D, resembling rails, is riveted to the shoring frame, and the other to the sliding side. They are connected by two steel box slides E F, joined by a rod G, so that they move together. Holes are drilled in the upper one E, by which it is secured by pins at any level; these pins are shown in Fig. 10.

The upper box slide E is first secured by two pins to the shoring frame slide, which is on the right-hand side of the figure. The side of the dock is now free to rise and fall, sliding through the box slides. As soon as the side comes to the desired level, pins are inserted through the slotted holes in the box slide E, and as soon as these pins take their bearing, the holes will also be fair to receive other pins, which will keep the side rigidly in position; the dock and sliding sides are now firmly attached. Instead of using pins to secure the box slide E to the sliding side, an alternative arrangement is to use a gib and cotter; this arrangement allows for any springing such as the most rigid iron structures are subject to. It will be remembered that the slides occur every 6 feet on both sides of the dock.

As already mentioned, one of the most valuable features of this dock is that it can readily dock itself on an even keel, without being taken apart or removed from its moorings; even the underside of the pontoon can, in less than two hours, be raised several feet clear of the water for examination and cleaning. To do this, the sides are lowered until their decks are level with the pontoon, they are then

Fig. 9.



secured in the manner already described, and are pumped out, thus raising the pontoon and the fixed corners well out of the

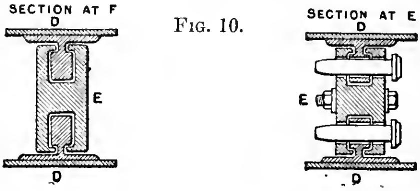
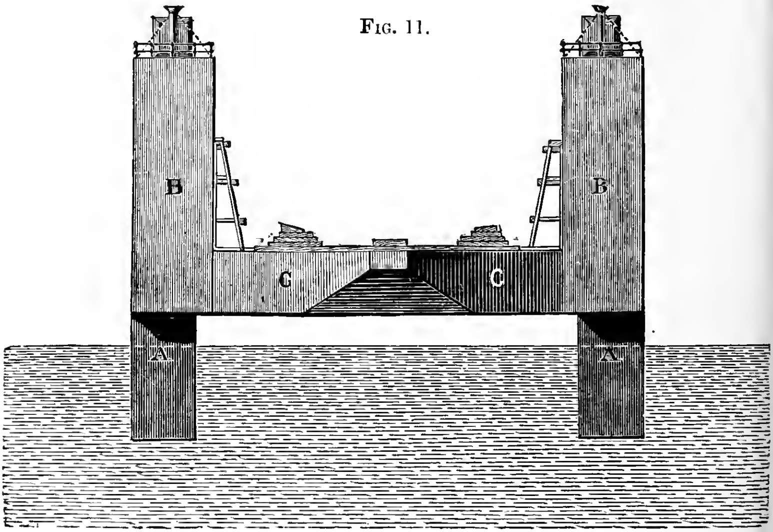


FIG. 10.

water, as shown in Figs. 11 and 12, leaving ample space for a boat or raft to pass under. Similarly, when the sides have been secured in their highest position, and the pontoon pumped

FIG. 11.



out, the bottoms of the sides will be raised clear of the water as shown in Fig. 13. In both these views the author has, for the sake of clearness, omitted to show the fixed corners.

The absolute necessity of being able to get at the bottom of an iron floating dock so as to clean and paint it periodically has long been felt, and many arrangements have been tried and more suggested for doing so, in order that the dock may be prevented from deteriorating more quickly than any other iron structure intended to be continually used in salt water. The Bermuda dock has to be heeled over to allow her bottom to be inspected, an operation so dangerous that it has been done once only, it is believed, since the dock was completed fourteen years ago. This dock is said to have cost the country 250,000*l.*; a double-power dock of the same lifting power would not cost

half that sum. By the iron sectional dock system of the Continent, each section of the dock can, in turn, be docked on the other sections; but this is a long and costly work, necessitating the dock being thrown altogether out of work for

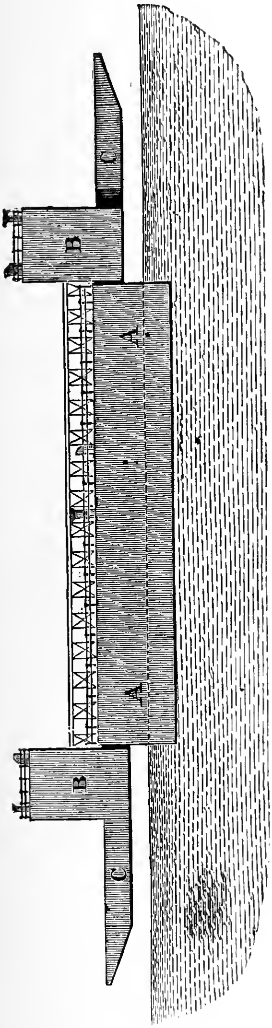


Fig. 12.

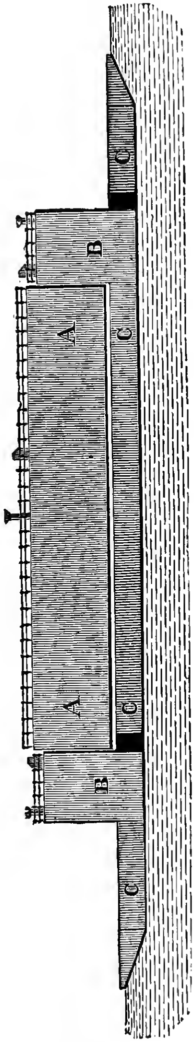


Fig. 13.

many weeks; all the rivets connecting the sections together have to be cut out and afterwards replaced. Supposing a sectional dock to be compulsorily put out of work for a month in the year, on the average, for the purpose of cleaning and

repairs, it has thereby lost one-twelfth of its money-earning powers, or, in other words, $8\frac{1}{3}$ per cent. of the dividend per annum; whereas the double-power dock can be rapidly self-docked and painted in a few hours at any time when work is slack, without throwing the dock out of work, and any repair required can be done promptly, so that there will never be much necessary. This dock can therefore earn a larger dividend than any other form of floating dock except the depositing dock already described.

At the first glance, it might perhaps appear that lowering one of the sides while the vessel is on the dock would dangerously reduce the stability, but that there is at all times excessive stability will be evident when it is remembered that the actual stability is due to the fact of the vessel and the other secured side of the dock being practically in rigid connection, and really forming one structure with a breadth about twice that of the vessel. Any movement toward either side is immediately resisted by immerging the vessel to a greater depth and by raising the fixed side out of the water to a corresponding extent, or vice versâ, the centre of gravity lying between the secured side and the vessel. At the time the side is lowered the vessel herself, being only half out of water, has nearly the same stability as when afloat, and any listing movement causes nearly the same displacement, bringing into play nearly as much righting power as if she were floating at her light water line. The sides of the dock are successively lowered and again secured long before the bilges of the vessel are raised out of the water, so that at the moment when the vessel ceases to add stability to the dock, the stability is more than ample, being that due to the two sides in combination.

The use of this dock is quite independent of tides and currents; it is specially suitable for exposed positions, and if necessary it can be provided with a closed end. Such a dock moored behind a large dolphin can easily withstand rough weather and heavy seas.

The double-power dock possesses the following advantages:—

1. It is very rapid in its action, having to lift less useless weight than any other form of dock.

2. It can rapidly dock itself in two hours on an even keel, so as to afford every facility for cleaning and painting all parts.

3. It has about double the lifting power of an ordinary floating dock for its size and weight, and its cost therefore is much less than that of any other floating dock.

4. It is suited for use in rapid rivers, and varying tides and floods, and in exposed positions.

5. It cannot sink, even if all its valves be intentionally left open.

6. It has the advantage over fixed stone or concrete docks of requiring no foundations, and of being quite independent of depth of water; it is thoroughly seaworthy, and can be easily towed from one place to another.

DISCUSSION.

The PRESIDENT, in opening the discussion on the paper, said that England being a small island having a large commerce, and also having to maintain a large navy, it was advantageous to be able to have floating docks constructed as economically as those which had been described appear to be. All countries would be able to have such docks at a small cost, and England could have them at different stations throughout the world for the use of her shipping, so that if a vessel broke a screw or damaged a plate it could be taken into one of the floating docks and repaired in a few hours. He read the paper before it was presented to the meeting, and even before he saw the diagrams he considered that it was a remarkably good production. He would propose a vote of thanks to Mr. Standfield for his paper. He regarded it as one which would be very useful to the Society and also to the world.

Mr. F. E. DUCKHAM said he had the privilege of being connected with the Victoria Graving Docks in its early days. It was an invention of the firm with which Mr. Standfield is connected. Sixteen hydraulic rams on one side of the Dock entrance each supported the end of one of as many sets of girders. The other ends of the girders were similarly supported by sixteen corresponding rams on the other side of the entrance. The vessel to be docked was floated over a pontoon submerged and resting upon these girders in their lower position. The hydraulic pressure applied brought ship and pontoon up clear of the water in about twenty minutes. The water passages of the pontoon were then closed and it became sufficiently buoyant to float with a vessel of 2000 tons to one of the eight repairing berths, leaving the lift free for lowering or lifting other ships. This had worked, and as he believed is still working exceedingly well. He thought, however, that the system now introduced possessed advantages even over the Victoria Dock lift, chiefly in removing the necessity for the hydraulic lift rams and their foundations. Both systems had very great advantages compared with the ordinary dry docks, notably in first cost, in time occupied in exposing and floating vessels, and in the greater facility with which repairs could be effected and paint dried in the elevated dock as compared with the dark pit of the old type of dry dock. Mr. Standfield would

no doubt inform them as to the relative cost; he should not be surprised to hear that accommodation for eight ships could be obtained by the depositing dock at less cost than that of two ordinary dry docks. As to time, he had known vessels to be docked lifted, examined, and lowered at the Victoria Graving Dock in one hour and a half, while the same operation at a dry dock would occupy two tides, or say at least fourteen hours.

Mr. Walmisley said he hoped that the meeting would not allow an important subject like that of the paper just read to pass without being duly discussed, although Mr. Standfield had explained his views in such a full, clear, and concise manner, that he had left no part of the invention undescribed; and the subject was also most ably and graphically represented in the diagrams. As to the system of dock which was designed by Mr. Edwin Clark, and to which Mr. Duckham had alluded as being in use at the Victoria Docks on the Thames—a similar dock was also made at Malta, and another at Bombay—the great difference between that dock and the one which had been described in the paper, was that in Mr. Edwin Clark's dock the lifting power was all in a fixed position, whereas in the present case it floated, and could be applied in any position. In the case of Mr. Edwin Clark's dock, the number of ships that could be repaired or that could be docked dry with one dock, depended on the number of pontoons which were used. In the dock now before the meeting, the number of ships which could be accommodated, depended upon the length of the depositing stage. The dock could go out to any part required and pick up a vessel and bring it in on to the depositing stage and repair it. The advantages in favour of Mr. Standfield's system were indisputable. He had always very much admired the introduction of the floating outrigger in the depositing dock. It was a very simple and clever idea, for by means of such an arrangement the side was always kept in a vertical position, whether the pontoons were underneath to pick up the ship, or whether they were floating with the ship high and dry. He thought that Mr. Standfield might add to his valuable paper a few remarks about the cost, especially as regards the double-power system. This would greatly increase the value of the contribution to the 'Transactions' of the Society.

Mr. Conradi said that he considered the arrangement consisted of one rigid beam, having a number of supports which were not continuous. In one place there was a pontoon, then there was a space where there was no support, and so on throughout the structure. If they considered the wave motion of the water, they would find that the different supports carrying the solid beam were submitted to different strains; and it was of

great importance to know whether the strains to which the different supports were submitted were projected to the ship, or whether the structure was so designed that the ship did not suffer in consequence of the varying strains which came on each pontoon. They could not say with certainty what was the amount of strain coming upon each pontoon, and in what manner the strains would be either received by the structure itself or projected to the ship. This was an important question with regard to the stability and safety of the ship, and he thought that it was important enough to call for some explanation. Therefore the objections which a ship-builder would take to a dock of this kind, would be that the ship seemed to be exposed to a series of very powerful strains, the distribution of which was unknown.

Mr. Grierson said that he thought that one of the most practical answers to the theoretical question of Mr. Conradi was that a dock of this kind had actually been in use for some years, and that many vessels had been docked thereon, and invariably to the satisfaction of everybody concerned. That the various owners of the vessels had been satisfied was shown by the fact that the same vessel had been lifted over and over again. There was practically no limit to the size of the vessels which could be docked; the great Russian circular ironclads, which could not be docked anywhere else in the world, had been lifted several times on the depositing dock. The largest of these ironclads was 121 feet in diameter. There was nothing else afloat with such a breadth, except the 'Livadia'; and as soon as she got out to Sebastopol she would be docked. There was no other dock of any kind in the world, fixed or floating, that could possibly take these three vessels, the 'Livadia' and the two circular ironclads.

Mr. Standfield said that Mr. Conradi had asked what would be the result which the varying strains of rough water would produce upon a vessel in the depositing dock. In the first place the paper stated that the depositing docks were specially designed for quiet harbours and sheltered positions. It was not proposed to dock vessels in the middle of the Atlantic or in very exposed positions. He would not recommend that a depositing dock should be used on a very exposed coast. In the dock which was built for the Russian navy, the pontoons were much longer than would be required for an ordinary merchant vessel. They were 72 feet long, while those for a merchant vessel would not be more than 55 feet long. This dock was put together and first used at Nicolaieff, where it docked the whole of the ironclads, and the fleet belonging to the Russian Steam Navigation Company, after that it was taken into two

parts and towed across the Black Sea, where it encountered some very heavy weather without sustaining any damage. It was not designed for such a voyage, although it accomplished it successfully; as to the question of cost, the hydraulic lifting-dock required for every vessel a pontoon in addition to the lift itself. A pontoon for a vessel of 1000 tons would cost about 9000*l.*, and the stage for such a vessel would cost about 1500*l.*, so that at least six complete stages could be obtained for the cost of one pontoon. The staging is only a sixth of the cost of the pontoons. A depositing dock with one stage would be equivalent in accommodation to two stone graving docks, and yet cost less than one. In Holland, where the depositing staging could not be so conveniently placed owing to the difficulty of obtaining good foundations, the double-power dock would be the most suitable, but in quiet harbours and sheltered positions where there was a great number of vessels to be docked, it was best to use the depositing system. Very few gentlemen had made any remarks on the double-power dock, although to his mind it was a very important dock, though, like every other floating dock, it had the disadvantage of only being able to accommodate one vessel at a time; and hence, as a dividend-earning dock, it bore no comparison to a depositing dock provided with a sufficient length of staging. But for exposed positions, where it was not advisable to use the depositing dock, the double-power dock would prove particularly suitable; it was seaworthy, and it could go across the Atlantic. It was well adapted for being towed and could go on an expedition anywhere. The great advantage of the double-power dock was that it could rapidly dock itself at any convenient time, and thus very economically be kept in a sound condition. Some floating docks which were made eight or ten years ago, had never had their underwater parts inspected since. There could be no doubt that they would ultimately disappear from corrosion.

The President said that any one could see how easy it would be to lift the docks and paint them. Mr. Duckham had said that the docks had not come into use in England. English ship builders were rather loth to begin a new thing; but he believed that circumstances would compel them by-and-by to have the double-power docks for the purpose of docking vessels abroad where there was no dock accommodation. He thanked Mr. Standfield very much for giving them a paper which was so useful, not only to England but also to foreign countries. England ought to set a good example in ships and in docking. If we could not do so, he did not know who could. Foreign nations might be thankful to Mr. Standfield one day for giving them such a valuable machine.

Monday, June 13th, 1881.

CHARLES HORSLEY, PRESIDENT, IN THE CHAIR.

THE PREVENTION OF SMOKE.

By A. C. ENGERT.

The author has chosen for his paper the title "The Prevention of Smoke," instead of "The Consumption of Smoke," as some style it, because it is his opinion that smoke once formed in the atmosphere cannot be consumed or burnt while remaining in the air, for the reason that every particle forming the smoke is surrounded by a thin film of carbonic acid, through which the heat cannot penetrate, so long as the particles are carried forward by the air. If this was not so, then no particle of carbon would be able to escape unconsumed from a furnace of 3000° of heat, and 1400° in the funnel worked by a strong blast, as was the case in a torpedo boat, as stated in *Engineering* of September 24, 1880.

When, however, the particles of smoke have settled down as soot, and fall in this state on a fire, or are confined in a chimney, the soot will of course burn rapidly, the heat having relieved the carbon from the acid, in the same way as the iron is melting when it is released from the oxygen.

If this theory upon examination should be found correct, as the author believes it will be, then the statement recently made by a learned professor, that by entirely preventing smoke we may increase disease, cannot be correct, as the carbon surrounded by the acid can have no effect whatever on the germs of disease floating in the air.

The cause of smoke, and its destructive effect on property on land and water, and on health, is too well known to the Members of this Society. The author may therefore pass on at once to consider how this nuisance is to be avoided, at least to a great extent.

Scientific and practical men have for many years tried their utmost to prevent the atmosphere being loaded with smoke or soot; and although several very ingenious inventions have been brought out, the public have seen very little progress in this direction. Towns are getting larger, more factories are being erected, and the smoke therefore becoming denser, so that the

sun frequently cannot penetrate into our crowded houses, or even streets. The unhealthy vapour remains where it is to poison life. This was proved by the numerous deaths in February, 1880. Then the public became alarmed. Dr. Alfred Carpenter and Dr. Little at the Social Science Congress at Edinburgh, both spoke at great length on the danger of smoke to the lungs and heart. Other professors followed, and the press was up in arms. The Health or Kyrle Society held meetings, at which even the Government was represented, and various modes of proceeding were recommended, such as the use of anthracite and coke.

It was stated by the press, that England was rich enough to pay for any invention, and therefore a means would soon be found of producing clear air. This statement is no doubt true in one sense, but not in the other, as there are already a number of scientific inventions on record but not as yet adopted. The reason of this is, perhaps, that the Act of Parliament is not sufficiently stringent; the apparatus for preventing smoke already known may be too expensive for general use, or its mechanism so complicated that it requires a high class of workman to handle it, or the apparatus may be liable to get out of order. Something, therefore, of a more simple construction is required, so that it may easily be applied to the vast number of existing furnaces. It is well known that a careful stoker can almost prevent smoke by placing the coals on the dead plate to get warm, thereby consuming the gases arising therefrom; but he cannot leave them there long enough, as he is obliged to move them farther into the furnace, and for this purpose the door must be opened. The cold air rushes in, and the densest smoke will instantly arise. The time that green coal smokes, depends upon circumstances; firstly, if the wind is strong and cold, and the boiler house not well closed in, then a greater quantity of cold air will rush into the furnace, the result being that the smoke is denser or will continue longer. Secondly, it depends upon how the coals are stored. A very dry coal will give out its gases easily, and in comparison little smoke, but if the coals have been kept on open ground, then the moisture of the air has been absorbed by them, the moisture being greater in winter. Damp coal generally produces three times more smoke than dry coal; and if one or two good showers of rain have favoured the coals, then the smoke is almost ten times as much as from dry coal. Of course the whole matter depends entirely on how much cold air is allowed to enter the furnace where the green coals are used.

When commencing the preparation of his paper, the author intended noticing what has already been done by others

towards mitigating the evil of smoke. He finds, however, that the Transactions of the Society already fully record the labours of previous investigators and inventors in this direction. On the 12th of May, 1862, Mr. Charles Young read a paper on the use of coal in furnaces without smoke, which treats of the subject down to that date; whilst on the 5th of May, 1877, Mr. J. Walter Pearse read a paper on the mechanical firing of steam boilers, in which he described the various appliances for mechanical stoking. By these two papers the Members will have been fully informed upon the history of the question from the year 1813, when it appears the first efforts in smoke abatement were placed on record. Of those whose inventive talents have since been employed in solving the problem of smoke prevention, the author may be allowed to mention the names of Stanley, Walmsley, Juckes, Wilson and Smith, Vicars, Dillwyn Smith, Deacon, Henderson, Frisbie, Holmes and Walker, and Holroyd Smith, all of whose inventions are fully described in Mr. Pearse's paper. They consist of apparatus for mechanically feeding and stoking the furnaces of steam boilers, and are for the most part complicated and costly arrangements, as Mr. Pearse's paper shows. No doubt many of the Members are acquainted with one or other of these devices, and will be able at once to realise the comparatively simple and inexpensive nature of the author's method of smoke prevention, which he will now proceed to explain by the aid of the models and diagrams.

Supposing a shutter could be placed resting nearly on the fire, some 18 inches from the front of the fire-bars, just where the coals had been pushed from the dead plate, as seen in Fig. 1, it would be found that by moving the coals to that point no smoke could be formed, as the draught would be cut off and all the gases arising would at once be consumed, or drawn in to the other part of the furnace. In fact the furnace being divided into two compartments, the front would form the gas generator, and the other the consumer. As it is rather difficult to place a shutter in the interior of the furnace, another mode may be adopted. For this purpose the furnace door is removed, and if possible the opening is enlarged to about 14 by 16 inches, and an iron box of that size is fixed to the boiler in front. The box is about 20 inches deep, or long, and has a sheet iron door in front. Within this box are rails placed on each side, so that a plate can be pushed forwards or backwards in the same. This cast-iron plate is divided into three or four parts, connected by joints or hinges. The back part of this shutter, which is farthest in the furnace, has cheeks so as to form a hood. This hood when pushed in from the front will cover about 18 inches

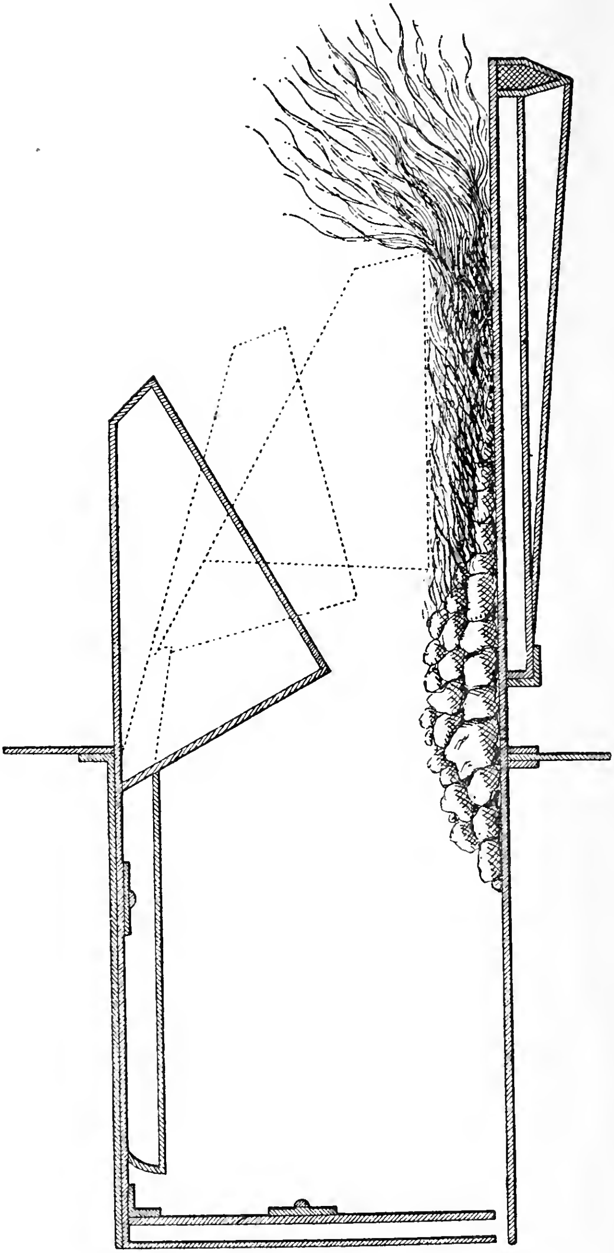


FIG. 1.

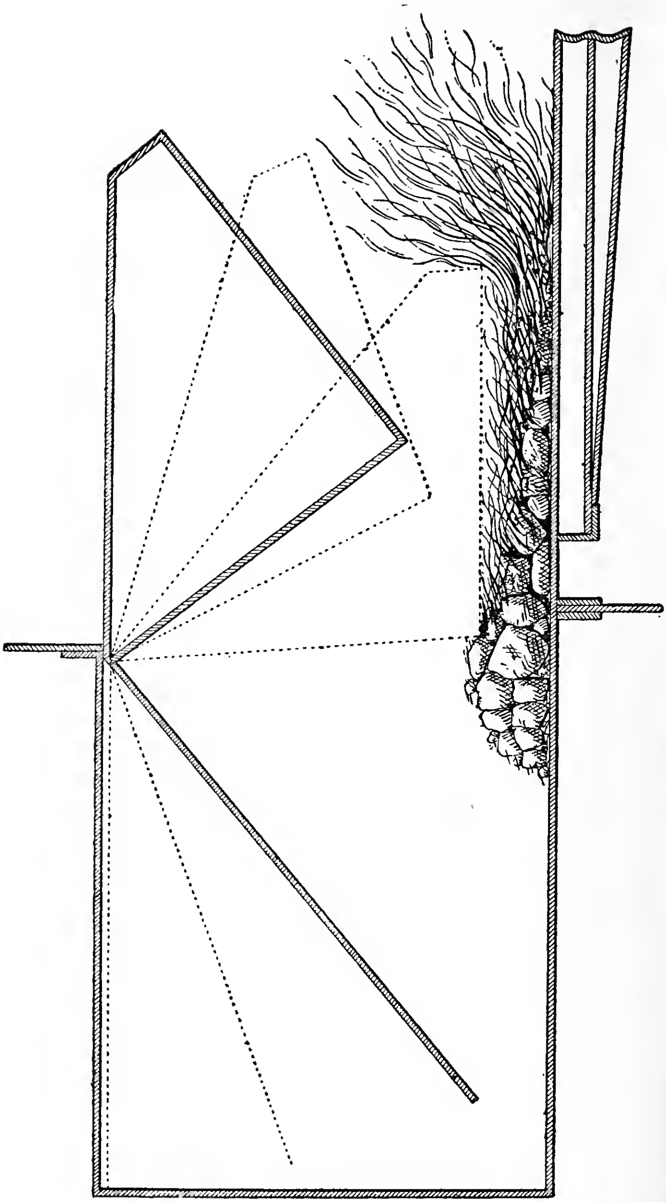
of the fire bars. Its nose resting on the fire, completely divides the furnace into two parts, and the draught is thereby almost shut off. In the front part, or gas generator, the green coal gets easily warm, and the gases arise; as cold air cannot rush in to condense the gases, no smoke can be formed.

It will be understood that when the stoker opens the furnace door he finds another door or shutter before him. To regulate the fire he is obliged to push a part of the shutter up and backwards, this will bring the back shutter or hood partly down. This shutter hanging down, will entirely prevent the cold air rushing into the furnace to cool the boiler, and still leaves room enough for the stoker to regulate the fire. When he has done this, fresh coals are required, and he is then obliged to entirely lift up, or push backward the front shutter. This brings down the nose of the hood in a slanting direction on the fire. The fresh coals are placed on the fire within the hood and box, the front door shut, when scarcely any smoke can be observed. After a few minutes the shutter or hood is partly or wholly withdrawn. The brightest fire may then be pushed farther under the boiler, the hood let down again, and the remainder of the fire pushed close under the hood, or fresh coals put on if required.

The apparatus as described has been at work for the last six months at the author's factory, 3 Mills Lane, Bromley-by-Bow, and has been there examined by practical engineers, who have expressed their satisfaction, and admitted the principle to be correct.

A still more simple apparatus, as seen at Fig. 2, can be made with the same result, if the opening or flue will admit a box of 18 or 20 inches high by about 18 inches wide and some 22 inches deep. In such a box, the shutters may be cast together in one piece in straight lines, at an angle of about 130°, to hang within the box on two pins or bolts. On the front of the shutter a rack is attached, passing through the top of the box to regulate the movement of this swinging shutter, that is to say when the front is up the back is down, and *vice versâ.* On the back part of the shutter the cheeks are cast, as explained in the preceding apparatus. It may be here remarked, that from the great heat, the iron of the hood expands, the hood is therefore made an inch or more smaller towards the point or nose, and the nose may be cast by itself and attached to the hood by two lugs, so as to be renewed easily should it become damaged by remaining too long in the fire through neglect. The extent of fire covered by the hood or shutter is some 18 inches on the fire bars, and generally 6 or 8 inches within the box, so that between the shutters a fire of about two feet will be kept.

FIG. 2.



The front shutter and door do not quite close at the bottom, so that there is a gentle draught from the front to admit oxygen to the gases arising from the coals within the box, and to aid their combustion, and to drive the gases into the other compartment, as the air passing through the grates and fire may not have sufficient oxygen left for the complete combustion of these gases. Another important point is, that by admitting oxygen as just stated, the damper may be lowered so that less heat passes into the chimney. If great heat or draught is required, then the damper ought to be wider open, the shutters placed half way and the front door open. The draught produced in this way is so great, that hardly any blast will equal it. The advantages of this apparatus are that the stoker is obliged to perform certain duties, which he otherwise may neglect. The cooling of the boiler is entirely avoided. The gases are consumed so that no smoke can be formed, or it is reduced to a minimum. As far as the author is aware, this is the only apparatus which can be easily applied to any existing furnace, and the only one by which, while hand firing is going on, no smoke is produced. The saving of heat and coals is considered to be from 16 to 20 per cent. As regards cost, a new boiler could hardly cost more than a pound or two more than one made without this apparatus. The author may here state that this apparatus is now being experimented on in two steamboats at Copenhagen.

The prevention of smoke in the ordinary open firegrate by the author was attended with some difficulty, as the feeding of green coals on the top of the fire, produces a dense black smoke, which is often prolonged and increased by the coals being kept in a damp or even wet cellar. Another matter of importance to be observed, is that in the ordinary firegrate the draught is strongest at the back, this being the nearest way to the chimney. The result is that the heat almost entirely passes into the chimney, and the coals in front of the grate are generally black. This causes a great loss of fuel, probably, on the average, about 75 per cent., and it is a source of discomfort to those in the apartment. To remedy the evils of smoke in open firegrates, many years ago a new principle was introduced, that of making the fire burn downwards, the coals being brought up from beneath. By this means, smoke was prevented, but the kindling flame so pleasant to look at was entirely banished, and the ashes remaining on the top prevented the heat radiating to the apartment. The principle was therefore abandoned. Since then various improvements have been introduced, principally having reference to ventilation, and they have met with more or less success. Most of them however,

produce smoke when coals are placed upon the fire, and the flue pipes in the walls have caused damage.

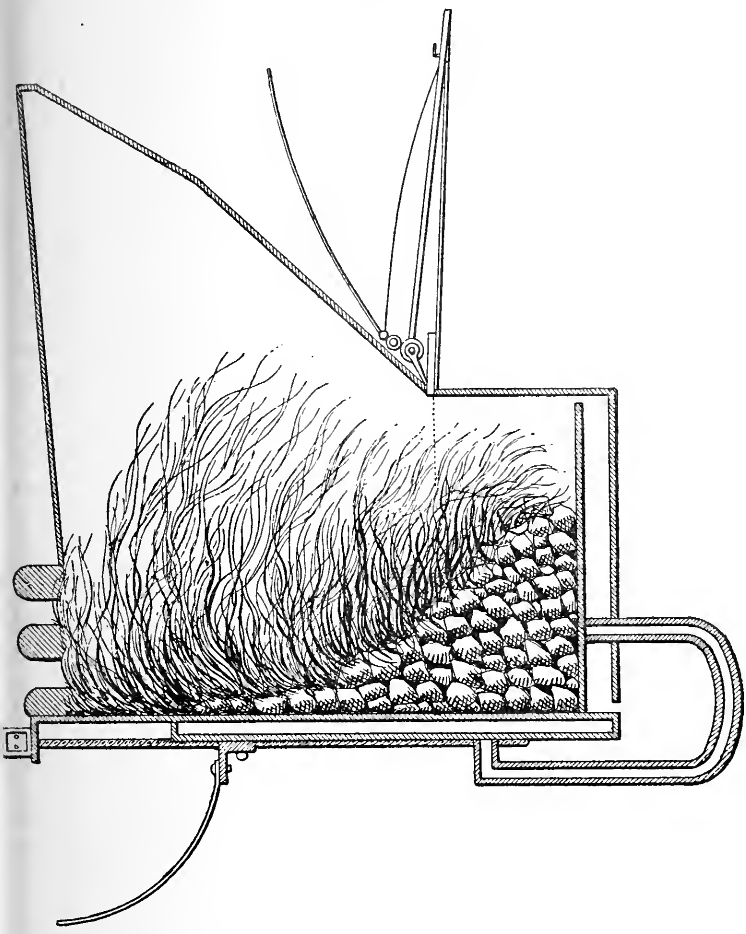
In the slow-combustion grate, in most instances, the fire looks black in front, and produces smoke when coals are put on. A recent invention is Dr. C. W. Siemens' firegrate, as explained by himself at his lecture in Glasgow in January last. He stated that according to Mr. Marback, it required 600° Fahr. to ignite wood and 700° to ignite coal, and that coal contains 16 per cent of its weight of permanent gases, as hydrogen, oxygen, and nitrogen, but when coals are in a retort, then 35 per cent. of gases are given off, including various materials. The doctor therefore argues that coals ought to be first placed in a retort to obtain the gases, and the coke burned in the open grate with gas jets under it for cheapness, and to prevent smoke, and at the same time always to have a bright fire in front of the grate to radiate its heat into the apartment. Of course this grate is specially constructed, but the coke cannot have that cheerful blaze so dear to the Englishman, the gas jets will be liable to choke with the ash, and rough treatment may damage the pipes and produce harm. As to the cheapness of the materials, upon which the doctor prides himself, something will be said farther on.

Much having already been said against using anthracite in ordinary firegrates, it is therefore unnecessary here to make any further remarks on this case. As the public have always been antagonistic to any innovation regarding their domestic institutions, the author proposes that the grate may remain where it is, and that it may be of the same construction, and further may burn bituminous coal as before, but by some slight addition smoke can be prevented. The author's plan is to remove the fire lump at the back of the grate, replacing it by a cast-iron box, open only towards the grate, and standing out at the back some 3 or 4 inches, as shown at Fig. 3. The bottom of the box laps over the grating some 2 or 3 inches for the purpose of fastening the box to the grate with two bolts and nuts from below. Within the box is a movable iron plate fastened to two guide-bars passing through the back of the box. These bars stand out at the back as much as the plate is to be moved forward, and are bent downward at a right angle, and again bent forward towards the front of the grate about 1½ inch below it. These two bars may, for the sake of cheapness, be riveted together to a sheet-iron plate, with ¾-inch holes drilled through the centre, for the purpose of placing the poker therein. By pressing the poker backwards against the front of the firegrate, the movable plate within the box will be pressed forward with the contents of the box. As the plate projecting out in front of the grate

would not look well in a drawing-room, a double cut screw is used which only shows a small head in front, and which may be made ornamental, and produces the same effect.

The box with the movable plate is filled with coals as well as

FIG. 3.



the grate; but before going further, another matter is to be considered, the draught must be regulated. To do this a plate is fixed under the grate, coming forward at the bottom, so that no draught can get behind, and leaving only a small part under the grate to the front for the draught, thus forcing the fire to burn bright in front. In order that the flame may not enter the

register, another small iron plate, resting on pins (which plate can be removed at will), is placed on top of the box, by which the flame is forced to burn in front. The working of this simple arrangement requires but little explanation. When the fire is lighted in the ordinary way, the box being filled with coals as well as the grate, smoke is of course produced at first, but as soon as the fire has burned for a short time, being obliged to burn in front the coals at the back are getting warm, giving out the gases which are consumed without forming smoke. When the coals have burned away in front, those from the back are brought forward by degrees, either by the screw or plate as stated. They are thoroughly warmed, and the gases, already mostly consumed, having been protected by the fire in front from the cold air, little or no smoke can be formed. When the box is nearly empty, the movable plate is pushed back, and the box filled with fresh coals. On the whole, barely one-tenth part of the smoke produced in the ordinary grate is produced here, and this tenth part is occasioned only when the coals cake so strongly that the poker must be used to break them, to allow the air necessary for combustion to pass. It will be seen that this apparatus can be applied to any of the existing grates. It is now in use at various places, including the author's house and offices. The advantages attending its use are very great, the gases arising from the coals are mostly consumed, thus giving heat instead of smoke, the bright fire and flame is in front instead of at the back of the grate, thereby giving warmth to the apartment, the saving of heat being at least half of that usually escaping into the chimney. One of the most important points is that coal dust can be used. On being pressed forward from the box into the fire, the dust will be found to be as hard as ordinary coal. Small coals, indeed, are preferable to large, as the gases are given out more easily, and no smoke can afterwards arise, this points to a further economy in the author's system.

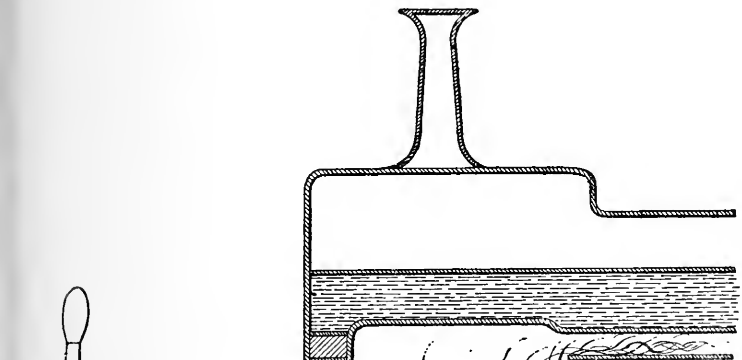
There are numerous stoves which have means for preventing smoke, but in kitcheners, and vertical steam boilers, up to the present time little or no attention has been paid to the prevention of smoke. The same box as used for the firegrate will, however, answer the purpose, and two can be fitted to a vertical boiler if required.

The invention can also be applied to locomotives, which is of very great importance. The railway companies are all in great trouble with their locomotives as regards smoke. Even the burning of anthracite coal will not entirely prevent smoke, and the best arrangements in use, as on the Brighton and other lines, have not up to the present time produced the desired

result. It is no doubt well within the remembrance of those present that the railway companies have been made to burn coke, but losing so much of its best heating materials, the use of coke was never properly accomplished, and therefore was discontinued.

In the author's system a box is placed under the foot plate, the whole width of the firegrate. The coals are then put into the box from the top, and the movable plate, being pushed forward

FIG. 4.



by levers, will supply the grate (including the corners so difficult to coal in the ordinary way), with good prepared coals, and as the bars slope downwards the coals are easily distributed over the whole grate with a rake, so that the door need only be open for a few seconds.

It has now been shown how the author's invention can be

applied to furnaces, ordinary firegrates, stoves, kitcheners, vertical boilers, and locomotives, the result in each case being little or no smoke, more heat, and a saving of fuel.

In conclusion, the author being a foreigner, although a naturalised British subject, asks the consideration of the Members for such defects as may have occurred in the present paper, which is the first he has had the honour of preparing on this subject.

DISCUSSION.

The PRESIDENT, in inviting a discussion on the paper, remarked that the subject of the paper was a very interesting one to all persons using coal. It was one which had been brought before the public many times. He was sure that if the author's plan would succeed, his paper would be welcomed not only by this Society but by all the scientific societies in the country.

Mr. ENGERT explained some models illustrating the application of his system for the prevention of smoke.

Mr. RIGG said that the author had shown very great ingenuity in his contrivances, and he was quite right that it was desirable to keep coals in a furnace from being subjected to any cooling action from the air required to sustain combustion. That object had been sought by a very great number of inventors of apparatus such as had been described. All these plans are really only so many mechanical devices for carrying out the same objects which the author had set before himself, and no variety in principle was involved in them. He thought that everybody must admit the general principle involved in all such contrivances to be perfectly sound. With regard to the chemical conditions which the author had laid down, he (Mr. Rigg) could not quite admit the idea that each particle of smoke, or unconsumed carbon, was surrounded by a film of carbonic acid, and not injurious to health while in that condition. The author had mentioned a number of names of persons who had devised furnaces for the combustion, or rather the prevention, of smoke, and he had very correctly drawn a distinction between prevention and combustion; but he seems strangely to have omitted to mention a pamphlet written by the late Mr. Charles Wye Williams, about the year 1855, wherein the very same distinction was drawn. That pamphlet, which was an exceedingly useful and excellent one, described pretty generally the lines which all subsequent inventors of smoke-preventing machinery had followed ever since.

As to the arrangement shown in Figs. 1 and 2 in the author's diagrams, it was, practically, a double door, and there was

no doubt that it would work, but whether practically for a long period remained to be seen. The firegrate in diagram No. 3 involved a very ingenious plan for replacing the coal sideways, instead of from the top, as usual, or from below, as some other inventors had attempted; but many present might be aware that if an ordinary firegrate be filled to about one quarter of its length with red hot coals, and then filled up with fresh coal, the fire would burn sideways without any smoke worth mentioning, and would remain alight for many hours, or even all night, and in the morning there would be found a red fire. This was a ready way for carrying out the same system which the author had devised, only it did not necessitate the making of the slightest difference in the arrangements which already existed in ordinary fireplaces. He did not think that in many houses of modern design there would be room enough in the back part of the fireplace for such a stove as Mr. Engert had designed.

With regard to the locomotive furnace, Mr. Engert's arrangement was one which had been adopted for years in other mechanical stokers, by means of which the coal was fed into the furnace without cold air being admitted. He had seen such mechanical stokers working very well, so that there was no doubt that Mr. Engert's contrivance might also work satisfactorily.

Mr. P. F. Nursey said it was quite true, as Mr. Rigg had remarked, that Mr. Engert's smoke-preventing apparatus was not much more than a double door, but it was a double door which was constructed in a very special and ingenious manner; for as one of the doors was opened the other was closed gradually, and both were placed at a peculiar angle. That was not the general action of double doors as ordinarily used. He himself visited Mr. Engert's works at Bromley-by-Bow a few months ago. There he found a boiler 18 feet long by 7 feet diameter, the furnace of which was working very well with Mr. Engert's apparatus. He watched the firing, and went outside expecting to see smoke, and he certainly saw perhaps a thin thread of smoke upon several occasions when the firing was done, but nothing more, and that lasted but for a few minutes. He came away convinced that the apparatus was a very perfect means of preventing the formation of smoke, and one which appeared to require nothing more than ordinary attention on the part of the stoker.

Mr. W. R. E. Coles, upon being asked to join in the discussion, said that he did not think that he should be right in making any remarks upon the practical merits of the invention which was the subject of the paper, for he felt that he was in the

company of men who were more able to express opinions on the mechanical merits than he was himself; and further, he was connected with a movement which brought before him a great many of the inventions of various persons, and he did not think that it would be fitting that he should express any opinion upon the merit of this particular contrivance. He should like, however to have the opportunity of saying that he attended the meeting because he knew that Mr. Engert was giving considerable attention to smoke-preventing appliances applicable both to boilers and to domestic grates. As the chairman had said, the subject was a very important one. The smoke abatement movement with which he (Mr. Coles) was associated had advanced to some considerable and practical proportions. It had held several public meetings, and was carried on by a committee which was influential both with regard to social position and scientific knowledge. They desired to have the co-operation of the Society of Engineers in the work, and to have the assistance generally of all persons who were interested in improving the heating art, for they regarded that as the real root of the smoke question. In addition to the interest which had been expressed in the movement in London, they had a large amount of sympathy expressed in the provinces, and they had had submitted to them practical inventions by which the smoke nuisance might be reduced. The Committee was about to hold at South Kensington an exhibition of the most modern means by which heat might be obtained without the production of smoke. The question was important both as regarded the health of the public and the consumption of coal. During the present year there had been an increase of 50,000 tons in the quantity of coal brought into London in the first quarter, and up to the end of May the increase was very nearly 90,000 tons. The coal consumption of Great Britain was increasing considerably, and we were no doubt very fast wasting our important coal resources. It was well known that agitators for smoke abatement had hitherto confined their attention chiefly to legislative measures dealing with industrial works. This did not seem to the smoke abatement committee to be fair, because perhaps as much smoke arose from domestic grates as from industrial works, and the committee wished to improve domestic fires as well as industrial fires. The present time, when new motors and new illuminants were coming forward, seemed to be a particularly favourable opportunity for directing public attention to the question of the prevention of smoke. The Press, which was a very important factor in dealing with a large public movement, had taken a very great deal of interest in the question. The committee included ladies as well as gentlemen. It would be conceded that when

the subject of domestic grates was being dealt with, it was important that the ladies should be satisfied with, and, as far as practicable, assist, the steps which were taken. Many of them had paid very great attention to the subject in abating smoke in their own houses. The committee did not wish for coercion. It aimed at educating the public as to the most reasonable way of obtaining heat. At the forthcoming South Kensington exhibition there would be public trials of apparatus, and there would be popular lectures for the purpose of spreading knowledge on the subject of smoke abatement.

Mr. Schönheyder said that he should have very much liked the author to give an account of some of the other plans which had been tried for the prevention of smoke, and to show the Meeting why they had failed, and in what respect his own plan was superior to the others. This would have enabled the Meeting, perhaps, to judge better of the value of the plan now before them. Perhaps the author might be able to make such an addition to the paper before it was published in the 'Transactions.' The author mentioned that he had found that more smoke was produced by coal which had been exposed for a long time to the weather, and which was, in fact, soaked with water. He (Mr. Schönheyder) was not aware that coal absorbed water to any serious extent. If it did so at all it must be to a very small extent indeed. Perhaps the author would be kind enough to say whether he had ascertained the quantity of water which coal actually absorbed. It was well known that coal deteriorated by being exposed to the weather, but this result was due to the fact that a slow combustion took place when coal was exposed to the weather through a portion of the combustible matter of the coal uniting with oxygen of the atmosphere. As to the method represented in figure No. 2 for the prevention of smoke in steam boiler furnaces, he failed to see how, on the plan there represented, it was possible to stoke a furnace with a length of 5 or 6 feet of grate. It appeared from the diagrams and models, that when the fire was stoked the flap on the left side had to be lifted up. This would cause the hood at the back to be depressed on the fire, and at the same time it would nearly close all inlet to the furnace; and it would be quite impossible to throw the coal to the further part of the grate. Again, he doubted very much, though, of course, he was open to correction, whether the furnace would prevent smoke without very great skill on the part of the stoker. He supposed that in general work the door would be in the position shown by the thick black lines. In that case, the hood would be lifted up away from the fire, and the air would come underneath the flap shown on the left side, and, instead of coming

into close contact with the fire, as it ought to do, in order to prevent smoke, it would go up over the fire. There were several exceedingly good plans before the public for preventing smoke. In locomotives, there was the simple plan of putting in a kind of curved plate which looked like a shovel, for the purpose of deflecting the air down upon the coal, and in immediate contact with it. This would prevent smoke to a very great extent if the fire was taken a little care of as well. The Martin fire door, which had been before the public a very long while, was another excellent invention. He had himself tried it with very great success. It consisted of a kind of flap, which opened inwards, and caused the incoming air to be deflected down upon the fire, and in close contact with the red hot coal. It entirely prevented smoke even with almost the worst coal that was met with. Mr. Engert's apparatus might answer its purpose if there was very great attention paid to the stoking. He wished to ask Mr. Nursey what was the length of firegrate which he saw at Mr. Engert's works.

Mr. Engert replied that the length was 6 feet 1 inch.

Mr. Schönheyder said that the plan shown in diagram No. 3 for preventing smoke in domestic fireplaces would, no doubt, work very well; but he doubted whether it was a new plan. Perhaps Mr. Engert was informed on that point. But, of course, they never could expect to get satisfactory heating for a dwelling-room with that barbarous contrivance, the open firegrate, and neither could they expect to get a good and economical result as long as they used a material so totally unfit for heating rooms as common raw coal. The open fire-grate, as at present arranged, converted the room into a huge and powerful vacuum box. The air therefore rushed in from wherever it could come in most easily. If it could come most easily from a sewer, it would do so. A constant stream of cold air was caused to rush along the floor of the apartment, so that the feet were kept cool, while the head was made hot.

Mr. Bernays expressed his agreement with the other speakers as to the importance of the subject of the prevention of smoke. The prevention of smoke had been tried for a great many years, and it had always struck him that not one of the many apparatus that had been designed for use in boilers and coppers and fire-places had ever been brought into real general use, except in a few cases under certain special circumstances. For instance, Jucke's furnace had been very largely used in breweries, where they burned spent hops under the coppers, and had very large grates at work day and night without any interruption. In all cases the principle aimed at by the use of the movable grates

which had been devised, was the same as that which the author had adopted for his own invention; namely, the feeding of the fire without the admission of cold air in front, or without the admission of more air than was necessary for the perfect burning of the fuel which was used in the grate. Mr. Engert's apparatus was very ingenious, but he should like to ask Mr. Engert whether he thought that it was likely to be more used in practice than other contrivances for the same purpose. With regard to the domestic firegrate, it struck him that the backplate, and the whole box behind, was very likely to be soon distorted into all sorts of shapes, and that it would be very likely to become burnt out, and fail to act as it was intended to act. For instance, the screw underneath the grate, being situated in the very hottest place, would be very likely to become distorted. There could be no doubt that the system was a correct one, and, for many years, he (Mr. Bernays) had been in the habit in his own house of putting the burning coals into the front of the grate, and placing the fresh coal behind, when he wanted a good fire. By this means the heat in the front of the fire warmed the coal behind, and he obtained, without artificial means, exactly the same effect as the author obtained by his apparatus. He should have liked to hear a little more said by the author on that part of the subject which was most interesting to engineers, namely, the application of the invention to the firegrates of boilers. He should like to ask Mr. Engert whether his invention had been used for Cornish boilers or Lancashire boilers.

Mr. Engert said that the invention was too new to have had the opportunity. The patents had only been taken out lately.

Mr. Bernays, continuing, said that, as engineers, they wanted to know whether such a hood standing right over the hottest part of the fire and consisting of comparatively thin plate of iron was likely to last long in practice if it was made much use of. On the whole, he had not the slightest doubt that the principle adopted was perfectly correct; and if the apparatus could be made to overcome the difficulties which would have to be encountered, it would effect a very great improvement in the way of using coal as compared with the ordinary method.

Mr. Alford said that he should like to ask the author two questions. One was with regard to the domestic grate. As far as he could see from the models, and also from the sketch, it seemed necessary that there should be some arrangement for the ashes. As at present arranged they would come right out into the fender. He should also like to know whether there was any arrangement for catching the ashes, and whether there

might not be some trouble occasioned by the coal getting behind the backplate, and causing difficulty in putting the plate back.

The President said that it appeared to him that if the domestic grate which Mr. Engert had described could be made to work by machinery, or in some way which would be independent of the attention of a domestic servant, the arrangement might answer; but if personal attention was requisite, there would, perhaps, at times be no one to screw the back forward, and the fire would probably be allowed to go out. He believed that the grate would fail to answer for domestic purposes because it was not self-acting, and the mechanical arrangement would get out of order very rapidly. He agreed with Mr. Schönheyder that they must do away with open grates altogether, and have one fire for the whole of the rooms. It would be well if the Government or the Local Board could step in when new houses were being built, and secure such an arrangement. In the case of an ordinary long firegrate for a tubular boiler, it would be found that if the furnace was under the care of a steady man, and the air was let in in a proper manner, the furnace would be practically smokeless. One plan of firing so as to prevent smoke, was to fire first on the right side after the furnace was once alight, and then, when the coal on the right side was ignited, to fire on the other side, and in that way to go on firing on the different sides alternately. This method was pursued at the Kent Waterworks, and he (the President) had never seen any smoke issuing from the chimneys at those works; small coal was used there and watered. He happened to be concerned for some large ironworks where coal was very cheap and where slack of all descriptions was used, some not being saleable. He had seen almost enough smoke there to make an eclipse; but after he took charge of the place, and when he carefully instructed the men as to the mode of stoking, a great diminution of smoke was the consequence. The change had been effected not by means of any expensive apparatus, but simply by the way that the coal was put on, and the air admitted through the furnace door. If the society which Mr. Coles represented would ask the policeman to do his duty round London, the smoke nuisance might be abated without any expensive apparatus. With regard to domestic stoves, the late Mr. John Sylvester, who was well known in connection with warming and ventilating, had brought out a stove in which the air was warmed underneath, and which made an ordinary apartment so warm that very little coal was wanted after the stove was once fired. As regards the use of coke and gas jets, he thought that some good might be done by means of such an appliance. He was

himself using gas in connection with asbestos. It was said that the use of gas jets and coke, was expensive; but if they would stop the air from going up at the back of the grate, and put a piece of iron or copper in the bottom, the gas would go in front and keep the coke bright, and they would thus obtain the most heat which could be got out of the gas. As to the author's statement that the gas jets would get blocked up, that would depend upon where the jets were placed. A scientific man could put them where they would not get stopped up. As to Mr. Engert's system for coaling as applied to furnaces, he would say nothing about it at present. There were many patents for preventing smoke in such cases, and he would not enter into any particular system. He would only say that if those who had steam boilers would show the stokers how to fire them, London might be freed from half the smoke which now arose from factories. He was sure that they must all thank Mr. Engert for having brought the subject before them.

Mr. Engert, replying to the discussion, said that one speaker had remarked that it was stated in the paper that smoke, being surrounded by a film of carbonic acid, was not dangerous to the lungs. He (the author) had not made any such statement. All he had said was that he thought that the smoke being thus surrounded, was unable to combine with any matter which was floating in the air. In reply to the objection that there would not be room at the back of the fireplace for the cast-iron box which was attached to his domestic grate, he begged to state that the cast-iron box did not require to stand out more than 3 inches from the back of the grate, and 2 inches would suffice for the bars behind, so that altogether five inches of space, or at the most, six, would be quite sufficient. There was nearly always room enough in the chimney to allow of such a space. One gentleman had said that the coals did not absorb much moisture. He (Mr. Engert) would like to know that if coals would not absorb the damp, how it occurs that when a smith makes his coals wet in order to get a greater heat, smoke immediately arises in considerable quantities. There was no comparison between a dry and a wet coal. The dampness in the latter when placed on the fire forms steam, and thus prevents the gases from being directly consumed. The same gentleman had objected that the furnace apparatus did not leave room for the stoker to stoke the fire. There was, however, a space of 9 or 10 inches, which he (Mr. Engert) was sure would afford sufficient room for the fire-irons to go along the furnace. Another speaker had said, and with truth, that there was in reality a slow combustion in his (Mr. Engert's) domestic grate. In an ordinary grate a strong draught from underneath is

produced, the flame going to the back, this being the nearest way to the chimney, leaving the coals in front quite black for some time. In his own stove the coal could not burn at the back. The fire and flame must both be in the front, and therefore the room would be heated more effectually than by means of an ordinary grate.

It had been said that the movable plate at the back of the stove might become warped and burnt. He (Mr. Engert) however had to say that this could not take place, the fire not coming sufficiently near to the plate to do it any damage. In fact before the fire could directly act on the plate, it would be out. A fire in his grate, burning Lambton coals, would last for six or eight hours, requiring only a little movement with the poker now and then to draw the fire forward. He had had such a fire burning for eight hours in his own house. As to the durability of the nose of the shutter or hood, in the apparatus for furnaces, if the hood was made of thin material it would soon crack, but if it was made of stout and hard metal, if would last three or four months. A new nose could be put on at a very little cost. The whole apparatus could easily be taken out upon the removal of the bolts. He, however, hoped in time to adopt a better material for the nose of the hood. As to the absence of an ash pan under his open firegrate, his invention had nothing to do with the provision of an ash pan, but there were some very nice contrivances for receiving the ashes to be had. If a little dust got underneath the movable plate at the bottom of the box, it would be pushed out as the plate is moved backwards, a small opening for the purpose being left at the bottom of the box at back, but such dust would only be trifling in quantity. With regard to his arrangement for locomotive furnaces, he had laid it before a very scientific engineer, and had been told by him that it was the very thing that had been wanted for years for railways, as in former times engines had been obliged to use coke, and the use of coke had never been satisfactory. The engineer in question thought that if his (Mr. Engert's) invention could be practically introduced if would produce a very good effect. He begged to thank the Meeting for the attention which they had paid to his paper.

THE VACATION VISITS.

The first excursion of the Society took place on Wednesday, the 22nd of June. Among those present were Mr. Horsley, President; Mr. Bernays, Past President; Mr. Williams, Honorary Secretary and Treasurer; Mr. Schönheyder and Mr. Nursey, Members of Council; and Mr. B. Reed, Secretary. A visit was paid to the Royal Mint. Admission was by ticket and only 150 tickets were issued. The Members and their friends witnessed all the operations of coining money, proceeding first to the melting room, and thence to the rolling and punching rooms, the press rooms, and finally the weighing rooms, in which they saw several of the nineteen automatic machines at work. Mr. Nash, Deputy Superintendent, and Mr. J. Newton accompanied the visitors and explained the various processes. The excursion was in every way successful.

The second excursion took place on the 20th of July, about 120 Members, Associates and their friends visiting Garrison Point Fort and Sheerness Dockyard, the party including Mr. Charles Horsley, President; Mr. Robert P. Spice and Mr. Joseph Bernays, Past Presidents; Mr. Jabez Church, Vice-President; Mr. Robert Berridge, Mr. William Schönheyder, Members of the Council; Mr. Alfred Williams, Honorary Secretary and Treasurer; and Mr. Bartholomew Reed, Secretary. The party proceeded from London Bridge by special steamer, and were received on the dockyard landing-stage by some of the authorities, by whom they were conducted over the works. In this dockyard are five dry docks, one closed basin, and two open or tidal basins. About 1700 men are employed on the general work of the yard. After passing through the fitting shop, which is provided with galleries, one devoted to light fitting work, and the other to pattern-making, the brass foundry and the coppersmiths' shop were next inspected, after which two Cornish engines of 50-horse power each were seen. These engines are used for pumping out the docks, and were erected over sixty years ago, and are still in excellent condition. The boiler shop was next inspected; it is used principally for repairing work. There is a good smithy of sixty fires and several steam hammers. Several of the visitors then proceeded to the timber yard, where wood-working machines are employed

in shaping up ship timbers. Some of the Members then visited the cable-testing department, where they saw cables up to 4 inches in diameter tested. A considerable portion of the work of this machine consists in re-testing cables that have been some time in use. It transpired that these old cables are not annealed before re-testing with the ordinary test of 8 tons per circular inch. Towards the end of the day a visit was paid to Garrison Point Fort, mounting forty-four guns, ranging from the 9-inch gun of 8 tons to the 12·5-inch gun of 38 tons and including the 10-inch gun of 18 tons. The fort is fitted with armour plates. In leaving the dockyard the steamboat steamed round the 'Hydra' turret-ship, which carries four 18-ton guns, and a few went on board the guard ship lying near it. This was a very successful excursion.

The third and last excursion of the year took place on the 17th of August. The Great Eastern Railway Company is making considerable additions to its goods depôt on the site of the old Bishopsgate Station—the premises will ultimately cover eleven acres—and to these works the visit was paid. Among those present were Mr. Arthur Rigg, Vice-President; Mr. W. MacGeorge and Mr. Joseph Bernays, Past-Presidents; Mr. Robert Berridge, Mr. Charles Gandon and Mr. W. Schönheyder, Members of Council; and Mr. B. Reed, Secretary. The visitors were received by Mr. Horace Willmer, Acting Engineer, who escorted them over the works. The depôt will consist of large warehouses supported on brick arches, and the waggons will be raised and lowered from and to the level of the rails by hydraulic hoists. The warehouses and arches contain upwards of 50,000,000 bricks and about 12,000 tons of iron girders and columns, and the station buildings might be contained in a square of 425 feet. A very extensive warehouse floor, calculated to carry 5 cwt. per square foot, covers the whole area of the main platform, and the largest wrought-iron girder supporting this floor has a span of 55 feet, and weighs 22 tons. To give some idea of the trade carried on at this terminus, it may be mentioned that the temporary fruit shed on the south platform receives regularly 300 tons of fruit per day in the season, and this enormous quantity is often exceeded. Thanks to the courtesy of the Railway Company in giving facilities, and to the kindness of their engineer, Mr. Willmer, and Mr. Vernon, the Members of the Society enjoyed an interesting and instructive visit.

October 3rd, 1881.

CHARLES HORSLEY, President, in the Chair.

IRON ROOFS.

By Arthur T. Walmisley, A.K.C.

The subject is a very extensive one, but much less has been written about the design of iron roofs than of iron bridges; and the author, having examined and collected together drawings of some of the details of various roofs for the purposes of his own study, thought a discussion profitable to the meeting might be raised in comparing the merits and objections of various systems of roof construction which have been adopted in different situations. His object is not to propound new theories, but to elicit valuable information from gentlemen who have had experience in the design and erection of iron roofs, and to point out examples to be found in practice, without attempting to describe minutely any particular covering, designed to meet special cases, or to state in detail the dimensions of the framework supporting the same.

When iron was first used in the construction of a roof it was only employed for those members of wooden trusses which were subject to tension, it being so much better adapted than timber to resist such strain; but as the machinery for manufacturing different sections of iron improved, its use became more general, and iron was substituted first for one member of a roof, then for another, until gradually the whole of the main framework was formed of this material in different forms. Hence we find that many of the early iron roofs closely resembled the form of construction adopted for ordinary timber trusses, the only alteration being in their section and detail of attachment at the joints. In a similar manner many iron arches of bridges resemble masonry designs, and are heavy and wasteful imitations. A comparison of Southwark and Westminster bridges at once shows the improvement made in our knowledge of ironwork at the time the latter was erected over the experience possessed when the former was built. The principal of the trussing of the roof over the House of Lords (see diagram No. 14) was a great

advance upon the old systems that had been adopted, but would probably be much modified if constructed in the present day.

The general use of iron in works of construction renders it desirable to arrive at the best form to adopt in different cases consistent with efficiency and economy. The primary characteristic or feature in the design of a roof is the main rib or principal, and it is the form of principal, whether truss or arch, which suggests the class or type that any particular roof may be distinguished by. Trusses may be best examined by comparing the bracing. No. 1 (see diagram), which was introduced during the early days of railway construction, is still within certain limits one of the simplest and best forms. The central strut supporting each rafter is held in position by the tie-rods which connect the head with the extremities of the rafter, and the horizontal thrust upon the supports is taken up by the tie-rod which connects the two struts and holds the trussed rafters together. A roof of this description may be seen in the side span of the Agricultural Hall, 36 feet wide.

The introduction of struts in a braced framework is with the object of reducing to a minimum the transverse stress that would otherwise be induced upon the members under strain. The roof over the Blythwoodholme Arcade, Glasgow (see diagram No. 16) is an example of a space of about the same width, covered with an arched form of construction.

A useful and economical adaptation of the type of truss shown in No. 1 (see diagram) is to be found in the Bristol Joint-line Station roof, designed by Mr. Francis Fox, of Temple Meads, Bristol, where the rafters are of a segmental form meeting at an apex in the centre, forming a rigid arch of 125 feet span, with a rise from springing level of 31 feet 3 inches, or one-fourth of the span (see diagram No. 17). Owing to the form of the roof and its considerable rise the side walls could be kept low, and some saving in masonry was thus effected. They are carried up 24 feet above the platform at the springing level, or less than one-fifth of the span. The circumstances of the site did not admit of any design which would exert an outward thrust upon exterior buttresses, hence tie-rods at the springing level were indispensable. The tie-rod rises in the centre 10 feet 5 inches above the springing. There are twenty-six principals, including two gables of ornamental design dividing the roof into twenty-five spaces at an average distance of 18 feet 9 inches apart. The purlins are of wrought-iron lattice arch construction, with horizontal bearing on top for the glazing, which follows the slope of the roof, and is raised at intervals on standards for ventilation. The roof is curved in plan, having a radius of 1000 feet along the outer wall, and a length of 500 feet measured along the

platform wall. No special provision was considered necessary with this form of construction for any play in the shoes into which the feet of the principals are secured. The principals if loaded equally are without transverse strain, but in order to provide against the effect of wind on one side or of unequal loading, as well as for the sake of appearance and the support of the heavy tie-rod, some light suspension-rods are added. The pointed form of principal was adopted chiefly because it harmonised with the general architectural character of the station buildings, and because some kind of curve in the principal appeared almost necessary for satisfactory effect in the case of a roof on a somewhat sharp curve. The price of iron was high at the time of the letting of the contract, and the roof cost 37*l.* 16*s.* per square of 100 feet measured on plan, including glazing and slates on boarding with all extras. The roof could, no doubt, be constructed for a less sum now. The High Level Station on the London Chatham and Dover Railway adjoining the Crystal Palace, Sydenham, is an example of a roof of the same width as the Bristol Station, divided into two spans of 62 feet 6 inches each. The type of truss adopted is also similar to that shown in diagram No. 1, consisting of upper segmental lattice ribs, having a total rise of 17 feet above the springing level, and rise of tie-rod in the centre 9 feet, forming a principal 8 feet in depth. The principals in each span divide the roof into 26 spaces, connected by five lattice purlins in each bay, and are placed 20 feet 6 inches apart, giving a total length of 533 feet.

The member which has the greatest influence upon the strains in a roof is the tie-rod. The result of raising it in the centre above the level of the points of support is to reduce the strength of the truss due to its diminished depth, or practically to throw more strain upon the component members of the roof, but additional headway is gained and a better general appearance presented. A good pitch for a roof with straight rafters is 1 in $2\frac{1}{2}$, giving a rise of principal equal to one-fifth of the span.

It is an essential feature in connection with the economy of all structures that the number of different parts should be as few as possible, but with spans of over 30 feet; if the top rib of the rafter be not constructed as in example No. 1 its length becomes such that more than one strut is necessary, and the rafter is supported at two intermediate points as in No. 2 of the same class, which may be adopted for spans up to 40 feet. Examples of No. 2 may be seen in the covered way over the approach to the Victoria Station, where the trusses are placed at moderate distances apart, and supported on

the bottom flange of transverse girders spanning the width of the railway. Other examples of longitudinal roof trusses carried on the bottom flange of transverse girders, may be seen at the Kentish Town and Camden Road Stations on the Metropolitan branch of the Midland Railway, where the girders are placed 21 feet 6 inches apart, and also in the side spans of the London Brighton and South Coast Railway Company's Station at London Bridge.

The roof over the Great Exhibition of 1851 also was supported on overhead girders of convenient length, with ridge and furrow covering. This method has been adopted on a large scale in the Bridge Street Station, Glasgow, which is divided into two spans of 114 feet and 49 feet respectively (see diagram No. 18). The large span covers the joint-line terminus of the Glasgow and South-Western Railway and of the Wemyss Bay Railway, the latter of which is worked by the Caledonian Railway Company. The smaller side span is over the main-line station of the Caledonian Railway, which is continued across the river Clyde into the Central Station or Northern Terminus. The joint-line station is covered by eight ridge and furrow roofs of small span, running longitudinally, carried on parallel lattice girders, which are supported on transverse girders of zigzag pattern, and trussed longitudinally with three sets of vertical angle iron bracing, uniting the upper side of the bottom flange of the transverse girders with the underside of the centre of the bottom flange of the longitudinal girders upon which the gutters rest. The ridge and furrow roofs are crowned by lanterns with louvres for ventilation. The main transverse girders are about 12 feet deep, and are continuous over both stations; they are nineteen in number and 31 feet 6 inches apart, the end transverse girder being filled in as a gable screen. The roof over the side span is open overhead for a width of about 21 feet transversely over the double line of rails from end to end of the station, the uncovered being divided from the covered portion by flat longitudinal vertical screens to protect the platforms. To allow of contraction and expansion on the main girders, oblong holes are cut in joint cover plates of the upper boom, the lower boom being fixed to the columns. The two spans are separated from each other by a row of columns supporting the main transverse girders. The cost of the ironwork only, in this roof, was 16*l.* per square.

The roof over the Central Station of the Caledonian Railway Company in Gordon Street, Glasgow, is somewhat similar in construction (see diagram No. 19). The covering consists of ten ridge and furrow roofs of small span running longitudinally, and carried on seventeen main transverse girders, which span the

whole width of the station. The total length of this roof is 560 feet, and the distance from centre to centre of supporting walls 213 feet 6 inches; the main girders are 20 feet deep, of zigzag lattice work, braced longitudinally with four sets of vertical diagonals in each bay, and horizontal lattice girders carrying the gutters. The end transverse girder is filled in with wood and glass to serve as a wind screen. The cost of the iron-work was 14*l.* 5*s.* per square.

The roof over the Citadel Station at Carlisle (see diagram No. 20) is likewise carried by transverse girders, but here the ridge and furrow covering runs parallel with the supporting girders, advantage being taken of the longitudinal diagonal bracing between these girders to carry the slopes of the roofing. The station is divided into two spans by columns placed about 40 feet 6 inches apart longitudinally. There are twenty-four transverse girders between the gables, dividing the roof into twenty-five bays. These girders are not continuous over the station but rest at one end on the side walls, their other ends meeting over the central columns. They are 15 feet deep, of single lattice pattern, which serves as transverse diagonal bracing between the roof trusses. These trusses are formed of light ornamental open cantilevers placed 15 feet apart and united in the centre between two girders supporting the gutters which run in a transverse direction across the station at a level of about 9 feet below the top flange of the main girders, the glazing being carried down to meet the gutters, while the ridge is supported on the top flange of these girders and raised to provide open side spaces for ventilation. Owing to the irregular width of the station, the main transverse girders are of varying length, their maximum lengths being 128 feet 3 inches and 154 feet 6 inches respectively. The cost of the ironwork was 28,850*l.* including columns, or about 12*l.* per square. The roof over the Oban Station of the Callander and Oban Railway is carried on girders of zigzag pattern 7 feet 10 inches deep, and 71 feet 6 inches span. They are placed at distances of 30 feet apart, and divide the roof into nine bays or spaces, the total length being 270 feet. These girders carry the ridge and furrow covering in a somewhat similar manner to the arrangement at the Carlisle Station; but in the Oban Roof there is an intermediate ridge and two gutters between the transverse girders as shown in diagram No. 21, the central portion of 15 feet span, forming the top of an A truss carried by these gutters, which are supported by open cantilevers attached to the main girders. The cost of the ironwork, including cast-iron supporting columns, was 2250*l.* or about 11*l.* 13*s.* per square. The engineer was Mr. John Strain of Glasgow.

The roof over the retort house of the Tunbridge Wells Gas-works, designed by Mr. R. P. Spice, consists of eight ranges or spans supported on transverse wrought-iron lattice girders of 65 feet span and 5 feet deep (see diagram No. 22). They are placed 25 feet apart from centre to centre longitudinally. Each span between the supporting longitudinal side walls of the building is divided into ten spaces, and the roof is carried by six main principals and five intermediate principals placed alternately and connected by purlins and wind ties. The main principals consist of straight inclined top flanges, with a curved lower flange struck to a radius of 14 feet having a rise of 7 feet above the springing. They are 2 feet 8 inches deep in the centre, and 3 feet deep at the springing, where they are attached to verticals in the girders, and are of lattice construction, the intermediate principals being formed of T iron.

The details of the ironwork in the Paris Exhibition of 1878 were well worked out, and were designed by the late M. de Dion, President of the Société des Ingénieurs Civils. The sites selected were those of the Champ de Mars and the Trocadero. The roofs over the industrial halls were each of the class shown in No. 1 (see diagram), with principals 82 feet span, placed 16 feet 4 inches apart. This form of truss and its adaptation to wide spans, as shown in diagram No. 10, is peculiar to iron roofs as distinguished from timber trusses, and represents the type almost universally adopted in France. The chief stations in Paris—the Gare du Nord, de l'Est, and d'Orleans—have principals of this type; the effect of the latter roof being very good. The system is light, and comparatively inexpensive. The span of the roof over each of the machinery halls in the Paris Exhibition was 116 feet 9 inches from centre to centre of supporting columns. The trusses were placed 49 feet apart, and resemble the class shown in No. 8 (see diagram), consisting of a straight upper and curved lower flange, connected by a system of bracing dividing it into eighteen panels, the inner flange springing from a bracket of the supporting column vertically for a distance of about 7 feet, whence it was curved towards the centre with the following radii: 24 feet, 49 feet 2 inches, and 119 feet 9 inches; the total rise from springing of the truss to the centre being 45 feet. In the connection of the purlins to the roof principals, allowance for expansion was provided for, by making the bolt holes at one end, attached to the bracket on the roof principals oblong, instead of circular. The grand Vestibule in the Champ de Mars building was formed by a semicircular arch, enclosing a flat screen, above which rested a central dome, forming the chief architectural feature of the construction.

The roof over St. David's Station, Exeter, erected about twenty years ago, is composed of trussed principals of the type of construction shown in No. 10 (see diagram). The details were designed by Mr. Francis Fox. The length of the passenger shed at Exeter is 360 feet, with principals 15 feet apart (centres) of 132 feet span, having a total rise of 22 feet, equal to one-sixth of the span. The principals are formed of rolled iron beams, fished with double fish-plates at their junctions, which occur at the place of the three tube struts in each half principal. The tie-rod is raised 5 feet above the springing level, giving a depth of truss of 17 feet. This mode of construction is simple, but as rolled beams are deficient in lateral stiffness, some parts of the roof, especially the glazed part, were stiffened by the addition of $\frac{1}{4}$-inch plates riveted to the top flange of the principal. The principals of the two outside bays at each end of the roof were also firmly tied together by angle iron bracing. The purlins are of timber, trussed with light iron rods, and placed about 4 feet apart. The roof was covered with diagonal boarding, upon which was laid Croggon's asphalted felt, and slated. This kind of roof was somewhat difficult of erection, owing to the considerable span and the absence of lateral stiffness in the section, but when once erected it was perfectly stiff. There are wind ties throughout the roof, which, with the help of the diagonal boarding from purlin to purlin, keep the roof rigid. The ends of the roof are formed of wrought ironwork of ornamental design, supported by a trellis girder, which is also supported towards the middle of its span by cast iron columns and a screen in the middle platform. The cost of the roof was about 16*l*. 10*s*. per square.

An example of No. 10, with a curved rafter, is found in the form of principal adopted at the Penzance Station of the Great Western Railway. The roof is about 250 feet long, and is divided into sixteen spaces by principals placed 15 feet $7\frac{1}{2}$ inches apart. The radius of the top flange of the principals is 68 feet 8 inches. The span of the roof is 77 feet, with a depth of truss equal to 10 feet 6 inches (centres), and rise of centre of tie-bar 2 feet above the springing level. The principals are connected by lattice purlins. There is no roller bearing, but a cast-iron bed-plate, having the surfaces in contact planed, is adopted, as the calculated expansion would be roughly only $\frac{3}{8}$-inch in length, which it is assumed the roof would be able to draw into itself in the case of contraction and *vice versâ*. The form of roof was adopted as the best to resist the strong winds which sometimes do considerable damage in the district, and the members forming the truss are attached together with

riveted joints, which were preferred to bolt connections. The cost of the ironwork was 1700*l.*, or about 9*l.* per square, and the total cost, including covering of zinc on boarding with glass, was 3000*l.*

The roof covering the Ealing Broadway Station of the Metropolitan District Railway, designed by Mr. John W. Barry, is formed of principals similar to No. 10, but with the struts fixed vertically as in diagram No. 15, it being considered that the fixed load and weight of snow act vertically. The roof is in a single span of 62 feet, with a depth of truss equal to 14 feet, and the principals are placed 21 feet apart, connected by vertical purlins, forming a roof 231 feet long. One end is closed with a gable screen carried by two horizontal girders, one at the springing level and the other between this level and the ridge, while the other end of the station is closed by the booking offices.

Diagram No. 6 shows a type of truss with inclined struts and vertical ties deduced from the queen-post truss, and is known as a queen-rod roof, the term "queen rod" being usually applied to the suspending rods analogous to princesses in wooden roofs. The roofs over the Euston Station of the London and North-Western Railway are of this form, in spans varying from 26 feet 6 inches to 62 feet 6 inches; and the same type has been adopted in the roof over their station at Bletchley, in spans of about 40 feet. The old Tithebarn Street roof of the Lancashire and Yorkshire Railway at Liverpool was constructed of this type in one span of 132 feet. The roof over the retort-house of the Dublin Gasworks, to which Mr. Jabez Church is consulting engineer, is carried by principals of this type—No. 6 (see diagram). The principals are 64 feet 3 inches span, placed about 6 feet 6 inches apart, and the feet of each rafter abut into cast-iron shoes, to which the tie-rod is fastened. The depth of the truss is 28 feet, and the rise of the tie-bar 5 feet above the springing. The oblique struts and vertical ties or suspending pieces have jaws or forks at their upper ends, where they are hung from the rafters by means of pins and screws, and at their lower ends, where they are connected with the struts and with the tie-bar by means of pinching nuts. The length of the roof is 296 feet 1 inch between end walls. Another example of No. 6 (see diagram) is to be found in the Swansea Station of the London and North-Western Railway, where the total width of 70 feet is divided into two spans, one of 64 feet 6 inches, and a side span of 5 feet 6 inches, the roof over the main span being composed of twenty-three principals 15 feet deep in the centre, with the tie-rod raised 1 foot above the

springing, and placed 20 feet apart. The purlins connecting the rafters are formed of wood, with a flitch-plate on each side, and about 6 feet apart. The roof was designed by Mr. H. M. Bradford. The cost of the ironwork was a little over 1500*l.*, or about 5*l.* per square. This form of construction was also used in the roof over the Great Northern Railway Station at Leeds, in two spans of 60 feet each, meeting in the centre on spandril girders supported by columns 20 feet apart. The roof is about 300 feet long, and the principals are placed about 6 feet 8 inches apart. The same type of truss has been adopted for the principals of the roof forming the Joint Committee's General Station at Perth, which is divided into two spans of 57 feet 6 inches each, meeting over a central row of columns. The principals are each divided into six bays and are placed 8 feet 2½ inches apart, with their outer ends resting on the side walls of the station. The engineer was Mr. W. Paterson. The roofs over the east and west courts of the Alexandra Palace, Muswell Hill, are also of this type No. 6 (see diagram), with principals 53 feet 6 inches span placed 17 feet apart, it being found cheaper to truss the purlins than to place the principals nearer. The roof cost 10*l.* per square, including fixing and columns without covering.

The ornamental roof over the courtyard of the India Office is carried by a compound truss. The span is about 66 feet 3 inches, and the rise of the ridge above the springing 16 feet 4 inches, which depth is divided into two (see diagram No. 23), the upper portion being composed of a truss 7 feet 6 inches deep, of the type shown at No. 6 (see diagram), but strutted at the base, below which is connected a trapezoidal truss about 8 feet 10 inches deep, with ends inclined in continuation of the pitch of the upper truss, and braced in a similar way, while the central portion is in the shape of a rectangle divided into three bays, and braced with inclined struts, connected by tension bars.

The roof over the Volunteer Drill Hall in Port Elizabeth is an example of No. 7 (see diagram). The principals are 70 feet span, divided into eight bays, the angle irons and bars being connected by rivets at the attachments. The total rise of the top rib in the centre is 15 feet 1 inch, and that of the tie forming the bottom rib 5 feet 9 inches above the springing, giving a depth of truss of 9 feet 4 inches. The roof is covered with galvanised corrugated iron, No. 20 B.W.G., laid on felt over ¾-inch boarding fastened to the timber purlins, which are secured to the main ribs by angle iron cleats. The ironwork cost 6*l.* 10*s.* per square.

In designing a roof for a foreign country, where skilled labour is scarce and expensive, it is advisable to offer every facility for erecting the different parts and to make them as similar and interchangeable as possible. Connections formed by pins or bolts are more easily fitted than those which require to be riveted together, and may be advantageously employed in a trussed roof, but riveted connections give greater rigidity.

Diagram No. 9 is a modification of the queen-rod roof, and forms a very good type of truss. It has been adopted in the roof of the Victoria Station over the London Brighton and South Coast Railway, designed by Mr. Jacomb Hood. The trusses are of 50 feet span, supported on trussed girders 10 feet 9 inches deep, which run transversely and form two spans of 124 feet 7 inches and 117 feet 5 inches respectively, meeting over the centre of cast-iron columns 1 foot 6 inches in diameter. Cast-iron gutters are fixed on the top wrought-iron plate of the girders, and constructed to take a part of the strain in the top flange. The ironwork cost about 20*l.* per square. The form of principal adopted in the Dover Harbour Station of the London Chatham and Dover Railway, also resembles No. 9 (see diagram). The span is about 44 feet, with principals placed 6 feet 6 inches apart and about 7 feet 6 inches deep, the rise of the top of the rafter being 9 feet, and the rise of the tie-rod 1 foot 6 inches above the springing. No. 6 is to be preferred to No. 9 for those roofs where it may be advisable to introduce longitudinal bracing between the principals in a vertical plane, and its vertical members are better adapted for roofs with hipped ends than No. 9; but No. 9 possesses the advantage of struts at right angles to the rafter, and, therefore, of minimum length; while in No. 6 the inclination of the struts is generally different in each bay, and the last strut nearest the support is usually at a very unfavourable angle for resisting compression. At the same time it must be borne in mind that hipped rafters are a considerable support to a roof, and resist the wind pressure better than a gable. A combination of No. 6 with No. 9 is found in some constructions in which both the struts and ties are inclined, the struts being placed as nearly at right angles to the rafter as the design will permit, and thus their length is shortened, as compared with No. 6, and the strain upon them reduced.

Diagram No. 8 combines the advantage of a straight rafter roof with the pleasing effect of a graceful curve to the inner member of the rib, the necessity of tie-rods being done away with. A roof 162 feet 6 inches in length, and 50 feet wide, was constructed upon this type, No. 8, for the Nitheroy Gasworks,

Brazil, in 1868. The principals are 6 feet deep in the centre, and are supported on columns placed 12 feet 6 inches apart. The roof overhangs 5 feet on each side at the eaves, which are supported by cast-iron brackets. Great rigidity is given to the structure by the attachment of the brackets to the ends of the rafters and to the columns. In every roof where the trussed principals are likely at any time to be subjected to partial loading, they should be counter-braced by cross diagonals between the verticals, and especially would this be necessary when erected with open sides in an exposed situation. The principals of the roof over the Wellington Pier, Bombay, were constructed similar to No. 8 (see diagram), and counter-braced throughout.

A good example of a Mansard or curb roof is found in the large span of the new North-Eastern Railway Station at Leeds, which may be described as consisting of two trusses of the type shown in No. 1 (see diagram), meeting at a height of 28 feet 6 inches above the springing level, and tied together at the feet, forming a principal of about 89 feet span (see diagram No. 13). The centre span and that on the opposite side are of the same type of truss, averaging 69 feet and 86 feet respectively; but to suit the conditions of the ground, and the arrangement of platforms, the three spans each vary in width. The principals are placed 12 feet $8\frac{1}{2}$ inches apart; and to resist the distortion due to a partial load, the centre of each side rafter is braced to the centre of the tie-rod, which is held up at the attachment by a king bolt. The merit of this truss is that nearly all the bracing is in tension, but the repetition of the tie-rods does not look well. The cost of the ironwork in this roof was about 22,000*l.*

Diagram No. 3 exhibits a truss of segmental form, with radiating struts connected by diagonal braces, and held in position by straining the tie-rods. This type of roof was adopted by Mr. Richard Turner in the old Lime Street Station, Liverpool, with a span of 153 feet 6 inches, divided into seven bays. The distance between principals was 21 feet 6 inches, which space was trussed laterally at each strut by purlins formed of three T irons, the centre T iron running direct from principal to principal, while those at the sides branched off right and left at 5 feet from each other, so that they were attached to the girder in three points. In addition, diagonal braces were fixed between two corresponding struts connected at the top with the purlins, and at the bottom in the adjoining principal with linking plates by bars of their own scantling. The ends of the principals were each fixed in a cast-iron chair resting on rollers

over the supporting wall on one side, and fixed on the other side upon a cast-iron column. The cost was about 20*l.* per square. A similar form of truss has been adopted in the Snow Hill Station, Birmingham, designed by Mr. Thomas Vernon, of Cheltenham. This roof is divided into two spans, meeting over a central row of columns—one roof is 506 feet long, carried by twenty-four principals of 92 feet span, having a rise of 27 feet 6 inches, with a depth of truss equal to 9 feet, the rise of the tie-rod being 18 feet 6 inches above the springing. The other roof is 176 feet long, carried by nine principals of 58 feet 3 inches span, having a rise of 17 feet, with a depth of truss equal to 7 feet, the rise of the tie-rod being 10 feet above the springing level. The principals are placed 22 feet apart, connected by purlins of two kinds, viz. trussed T irons and lattice girders. The cost, including covering for the roof proper, was 13*l.* 4*s.* per square.

The circular or segmental form is the best adapted for wide spans, but in any very exposed situation both the last described roofs, as shown in No. 3 (see diagram), would prove defective, as the counter-bracing applied to the centre bay is not extended to the side bays, so that when not uniformly loaded some of the ties are called upon to sustain compressive strain. In the Fenchurch Street Station roof, of 105 feet span, designed by Mr. G. Berkeley, in 1851, this contingency is provided for by counter-bracing every bay, as in No. 5 (see diagram), where the struts are vertical. The roof over the new grain depôt at the Millwall Docks, designed by Mr. F. E. Duckham, and now being erected, consists of twenty-one spans of 44 feet each by 211 feet, supported on columns 15 feet high, placed at distances apart of 15 feet, and connected by trussed angle-iron purlins. The main ribs are similar to No. 3 (see diagram), with radial struts, but properly counter-braced, as in No. 5. Each rib is divided into six bays, and is 8 feet 9 inches deep, the tie being nearly horizontal (see diagram No. 24).

Diagram No. 5 represents a truss on the bowstring principle, in which the verticals are constructed to act in compression while the inclined braces are considered to act in tension only. This form of roof was adopted in the Joint-line Station, at New Street, Birmingham, which comprises one of the largest areas in any single span. Its length is 840 feet, divided into thirty-five spaces by principals placed 24 feet apart, and varying in span from 212 feet to 190 feet 9 inches, with a rise of about one-fifth of the span. Each truss is divided into thirteen bays, and the depth of the widest is about 23 feet, with the tie-rod raised about 17 feet 6 inches above the springing level. The

main ribs are connected longitudinally by trussed timber purlins 8 feet apart, resting on the back of the principals and butting against one another, thus forming continuous lines from end to end of the roof, which are maintained by wind-ties springing from the foot of every alternate arch, and running diagonally across the roof to the foot of the fourteenth arch on the opposite side. The trusses are fixed on one side over brick pilasters, and on the other they rest on rollers placed over iron columns 2 feet in diameter, which act as pipes to convey away the water. The roof is terminated at each end with a gable screen, and ventilated at the top along the centre by an elevated ridge resting on louvre standards. It was completed in May 1854, and cost 17*l.* 15*s.* per square. The roof over the west-end terminus of the South-Eastern Railway, at Charing Cross, is divided into fourteen spaces by fourteen principals, in addition to the gable principal. The clear span is 166 feet. The principals are trussed in a similar manner to No. 5 (see diagram), and are placed 35 feet apart. Each truss is divided into nine bays. The rise of the tie-bar is 25 feet, and of the curved rib 45 feet above the springing level, giving a truss 20 feet deep at the centre. The trusses are fixed at one end and hinged to a saddle bearing at the other. There are no wind-ties, but two intermediate trussed frames are introduced in each bay, with lattice girder purlins resting on the lower flange of the rib of the principal, and attached securely to the principal at the top and bottom flanges with slotted holes, the purlins being all bound together by the intermediate framed ribs and the riveted sash bars. The roof cost 40*l.* per square. The roof over the City terminus of the South-Eastern Railway, at Cannon-street, is trussed in the same way, and is divided into nineteen spaces by twenty principals, including gable. The principals have a clear span of 190 feet $4\frac{1}{2}$ inches, with a rise of curved rib at the centre equal to 60 feet and rise of tie-bar 30 feet above the springing level, giving a truss 30 feet deep. The principals are placed 33 feet 6 inches apart, and are connected by purlins extending from rib to rib, and secured by bolts, with holes slotted to provide for expansion and contraction. The purlins are braced by one intermediate rib in each bay and by the sash bars and boarding. The cost was 49*l.* 10*s.* per square. Both roofs are crowned with lanterns fitted with side louvres for ventilation. The main roof of the London Bridge terminus of the London Brighton and South Coast Railway is another example of this type of truss—No. 5 (see diagram). The span is 88 feet and the depth of truss 18 feet, the rise of the top rib being 27 feet and of the tie-rod 9 feet above the springing

level. The principal trusses are placed 16 feet apart, with a light intermediate rib of trussed angle irons resting on the wrought-iron purlins.

In the recent competition for the proposed Exchange Station at Liverpool, the design which obtained the first prize consisted of three spans, each something over 100 feet, of the type shown in No. 3 (see diagram), with vertical struts. If the diagonal members of the truss are constructed as struts as well as the vertical members, then cross diagonals would not be necessary; but in this case bracing as in diagram No. 5 should be preferred. A better arrangement where all the members are constructed as struts between the upper and lower connection is that shown in diagram No. 11, an example of which is found in the principal of the main roof over the Blackfriars passenger station of the London Chatham and Dover Railway. It is 87 feet 3 inches in span, and supported on columns 32 feet 3 inches apart. The columns are connected longitudinally by a trussed girder which carries two intermediate ribs. The rise of the top curved rib is 22 feet and of the bottom rib forming the tie 13 feet above the springing, giving a depth of truss of 9 feet. Ventilation is effected through the purlins, which are of cast iron, having ornamental perforations for that purpose. The total length is 401 feet 6 inches, and the whole roof is braced together by diagonal wind-ties. The columns are hollow, to carry off the rain-water. The roof was designed and erected under the direction of Mr. W. H. Thomas. The roofs over the Woodside Station, at Birkenhead, are constructed in a similar manner. There are two spans of 97 feet 11 inches and 91 feet respectively, supported on the side walls of the station and meeting in the centre over a longitudinal row of columns placed 25 feet apart. The principals resemble No. 11 (see diagram), and are 10 feet 4 inches deep (centres), with a rise of 25 feet from the springing level to the centre of the top rib. They are fixed in the centre to the columns and spandrils, but at the other end the shoes are provided with expansion rollers resting on the wall plates. The roof is divided longitudinally in fifteen spaces by the main ribs, and surmounted by a longitudinal skylight 16 feet wide, with side louvre standards. The north-west corner is curved in plan, owing to the position of the site. The purlins consist of trussed T iron, and the whole is braced by diagonal wind-ties connecting three bays. The roof was built in 1877, and cost about 32*l.* per square. The roof over the new Lime Street Station, Liverpool, is also composed of trusses framed as shown in No. 11 (see diagram). The main portion, erected about ten years ago, consisted of principals of varying span, averaging 212 feet, with a depth of 22 feet

9 inches, measured from top of truss to arch of tie, which is raised 22 feet above the springing level. The station was enlarged in 1875. The span of the extension measures 191 feet, with a height in centre of 71 feet. The wrought-iron principals are similar in construction, and are placed 32 feet apart, connected by lattice purlins placed over the ribs, and provided with ventilators supporting the wood purlins upon which the sash bars rest. The junction of each strut with the tie-bar is effected by a turned steel bolt and nut. The principals are fixed over a double line of columns placed longitudinally at the junction of the spans. The columns are 20 feet high, with a mean diameter of 3 feet. The length of the roof is 645 feet, and cost 30*l.* per square, exclusive of gables.

The loads on a roof are partly permanent and partly occasional. The weight of snow varies in amount in different countries and in different positions. As in this country snow is not likely, in the presence of a strong wind, to accumulate on a roof more than about 9 inches in depth, it is unnecessary to allow for a greater distributed load than 8 lb. per square foot of horizontal surface covered. The pressure of wind is more variable, as it does not always blow in the same direction. In finding the strains on a roof, it is incorrect to assume that the wind force acting vertically is the worst case that could happen. Its pressure depends not only upon its velocity, but also upon the angle of incidence at which it strikes the roof. It is difficult to determine the limits of this deviation from the normal, but it may be estimated approximately, and the effective normal pressure of the wind acting at any point on the space between the main ribs calculated, while the non-effective tangential pressure may be practically disregarded. In this country it is sufficient to allow for a horizontal pressure of 40 lb. or 45 lb. per square foot of surface directly opposed to it, acting broadway on either side of the roof, as representing the equivalent of wind and snow pressure; indeed, it is the opinion of many engineers that this amount is too much. All roofs settle a little, so that it is advisable with large spans to fix the trusses at one end only, and it is found the most economical plan to fix the side opposite to that on which the heaviest gales are likely to blow. In the annexed diagram (No. 25) the inclined dotted lines attached to the truss represent the direction of the resultant pressure produced by the wind force and dead load, and the length of the lines in the diagram of strains show the respective amount of strain in the different members of the truss. Thus it will be seen that the truss fixed on the leeward side, and left free to expand or contract on the windward side, has the amount of strain in its component parts greatly diminished when com-

pared with the same truss fixed on the windward side, the data in each calculation being alike. The thick lines show the members in compression, and the thin lines those in tension, while the black dotted lines show the external forces, the greatest stresses being when the leeward foot is free. A simple form of truss has been assumed to illustrate the principle, but the result would be similar in any case, and shows the economy to be effected by observing the direction of the prevailing wind in any situation, and fixing the roof principals as near as possible on the leeward side.

For moderate spans, bearing surfaces accurately planed are better than small rollers. Roller frames may tend to lessen the racking motion produced by expansion and contraction of an ordinary roof, but do not prevent it. An examination of the Exeter Station roof of 132 feet span, some time after its erection, proved that the rollers which had been provided at the shoes to the principals in the outer wall had not moved, so that they might have been dispensed with. During the Hammersmith Bridge inquiry in 1869 it was noticed that the rollers under the chain connections in the towers had rusted into their saddles or bearings, there being evidence of the chains having rubbed their under surface upon the rollers, rendering the friction of the rollers so great as to require the tower itself to ease before the rusty rollers would rotate. Mr. Brunel nearly always provided for variations of temperature in his structures; but time and practice have since proved the effect to be much less than was at first supposed. Care should, however, be taken that the wall or other support at the fixed end of a roof of a large span is capable of resisting the thrust produced when the wind is blowing on either side of the roof with its full force, and the rollers at the other end are on the point of motion; also that the support at the roller end is capable of sustaining the pressure under every variety of loading. The wind pressure may at any moment act in a vertical direction, depressing the main rafters and producing an uneven stress upon the connection at the ends, which causes the roller on the inner side to be more compressed than the others, and tends to crush it. In the Cannon Street roof, provision is made to prevent this by attaching the end of the principal to a special casting, which is connected to another casting resting on the rollers by a circular joint secured with a pin; so that, whatever the inclination of the main rib may become, the hinging of the joint causes the stress to pass through the centre of the group of rollers, and thus to be evenly distributed over them. It is usual to brace a roof

diagonally, to enable it to resist the effects of wind blowing at an angle with the axis of the roof, by iron ties passing up from the springing to the ridge in an oblique direction and attached to the underside of the purlins. In some part of the length of these ties a coupling screw is inserted to admit of proper adjustment. In many roofs these wind ties are spread all over the structure. In the roof over the Drill Hall, Forrest Road, Edinburgh, designed by Mr. R. H. Bow, the wind bracing is confined to two bays. The roof consists of principals similar to No. 12 (see diagram), with a span of 97 feet 6 inches, fixed at one end and resting on rollers at the other. There are nine of these trusses 13 feet 6 inches deep, which with two stone gables give ten equal bays in a total length of 135 feet. The bays next the end bays are braced with diagonal ties fixed throughout at a favourable angle, the lateral stiffness of the six intermediate and of the two end bays being secured by their purlin connections. The radius of the curve of the top flange of the principals is 57 feet 6 inches, and the rise of the tie-bar in the centre is 13 feet 6 inches. The wind-ties are connected to the lower face of the upper angle irons of the arch, underneath the purlins which are attached to the upper face. Besides looking well, this disposition offers facilities in the erection.

Diagram No. 4 illustrates a queen-post truss derived from the old timber system, but generally modified in its recent application to iron structures. The roof over the Earl's Court Station of the Metropolitan District Railway, designed by Mr. John Wolfe Barry (see diagram No. 26), consists of principals formed of two inverted queen-post trusses, with vertical members braced together and connected by purlins, which are made deeper at their junction with the principals than in the centre, so as to stiffen the ribs longitudinally. The principals are about 96 feet span, and are placed 20 feet apart. One end of each principal rests on a single steel roller. The purlins are not at right angles to the rafter, but vertical, as in the roof over the Ealing Station (see diagram No. 15). There is no wind bracing throughout the roof, but diagonal bracing in the two end bays, which counteracts the endways pressure of the wind. The roof is closed at one end by the booking-offices, and at the other end with a gable screen formed by trussing a main rib longitudinally as well as bracing it transversely. Provision is made for ventilation in standards fixed over the purlins. The roof over the Broad Street Station belonging to the London and North-Western Railway is in two spans, of 95 feet each. The principal resembles a queen-post truss shown in

No. 4 (see diagram), but was originally designed to act as a tied arch braced with tension rods. In each side-inclined rafter one vertical strut is inserted, to obviate the effects of unequal loading. The principals are placed 36 feet 10 inches apart, resting on the outer walls, and meeting over a central line of columns which are connected with wrought-iron lattice spandril girders. The principals are about 12 feet 6 inches deep in the centre, and the rise of the transverse tie-rod is about 4 feet 6 inches above the springing level. Each span is surmounted in the centre with a cast-iron arched spandril ridge, to which are attached side louvres for ventilation. The whole roof is well secured by wind-ties, which the construction here adopted renders especially necessary to maintain the structure in position. The roof was erected in 1865. A similar form has been adopted in the roof over the Preston Station, consisting of principals placed 32 feet apart, the spans in one length varying from 77 feet to 47 feet connected on one side to spans of 51 feet, and on the other side to spans of 33 feet over the platform buildings, there being an additional outside length of spans varying from 66 feet to 50 feet, forming a covering about 992 feet long by a varying width in four spans.

The type of roof adopted at the west-end terminus of the London Chatham and Dover Railway—Victoria Station—also at the Central Station, Liverpool, and Queen Street Station, Glasgow, may be described as a tied arch with the tie-bar looped up, the tie taking the place of abutments to resist the thrust of the upper part of the arch. The roof at the Victoria Station consists of two crescent arches of unequal length and unequal span, as it was found necessary in order to meet the then existing arrangements of the station to make one span 127 feet 4 inches wide, and the other 129 feet wide, the length of the former being 455 feet, and of the latter 385 feet. The principals are 21 feet deep from the centre of the top rib to the centre of transverse tie, which is raised 8 feet 6 inches above the springing line. They are placed 35 feet apart, with two intermediate ribs springing from the gutters resting on cast-iron spandril girders, which connect the top of the columns under the feet of the principals together. The covering is supported by eight trussed and six trellised purlins, which are bolted to the main ribs, and every two bays are braced with diagonal wind-ties. The outer gutters rest on the side walls of the station, and the middle columns serve as pipes to drain the central gutter. Expansion rollers are provided under the foot of each principal over each side wall. Ventilation is obtained by a raised covering, trussed as in No. 1 (see diagram), over the

centre of each roof. The work was designed by Mr. John Fowler, and the cost altogether was 27*l.* 13*s.* 4*d.* per square. The roof over the Central Station, Liverpool, is similarly constructed. The main ribs are 160 feet span, with a rise of 40 feet in the centre, the tie also having a rise of 14 feet. This roof is one of the boldest designs of its kind, the principals being placed at the unusually great interval apart of 55 feet to meet the requirements of the adjoining buildings. There are nine principals, one of which supports a gable screen, which is trussed against the action of the wind, while the other end of the roof is closed by the station buildings. The main ribs are connected by lattice purlins, which support five intermediate ribs. The tie-rods are of steel. The roof is 495 feet in length and is ventilated by open spandrils carrying a raised skylight along the ridge. The roof was designed by Mr. John Fowler, and the cost of the iron and steel was 14*l.* 1*s.* per square. The roof over the Queen Street Station, Glasgow, belonging to the North British Railway Company (see diagram No. 27) is about 415 feet long, and 170 feet span from centre to centre of supporting columns, which are placed at a distance of 41 feet 6 inches longitudinally. This roof is the largest span of its kind, and is carried by nine principals in addition to two end gables. The rise of the centre of the top rib of the principal is 44 feet, and the rise of the tie-rods 14 feet 9 inches above the springing level. The side columns are connected by lattice girders carrying the gutter, and each bay between the main ribs is divided into five spaces by four intermediate ribs supported by lattice purlins placed 27 feet 9½ inches apart, with secondary purlins carrying the glass. The tie-rods are of steel. The roof cost 15*l.* per square, exclusive of foundations and drainage. There is not so much difference now as there used to be between the prices of iron and steel, and hence steel is being rolled into a larger variety of sections than formerly. With roofs of small span the weight of the component parts is not sufficiently great to effect any economy by the substitution of steel for iron, but in large spans the saving of expense is sufficient to recommend its use as presenting a much lighter appearance than iron of equal strength.

The general adoption of iron roofs of large span is comparatively of recent date. Beyond a span of 50 feet, the question arises whether the roof shall be made in one or more spans. The late Professor Rankine held the opinion that the roof should, where possible, be in a single span over the whole station, but the late Sir Charles Fox preferred roofs of 50 feet or 60 feet spans as being the cheapest. If intermediate pillars are

used, they should be placed in the middle of broad platforms. A comparison of the two stations at Victoria, London, shows this. In the case of the London Chatham and Dover Railway Station, they are now in the centre of the narrowest platform, whereas, in the London Brighton and South Coast Railway Station, they are in the centre of a broad carriage road. Of course, the adoption of very large spans is more expensive than dividing the space into two or three moderate spans, but there are the advantages of (1) freedom from all intermediate supports, giving facilities in laying out the space to the greatest advantage, or in subsequently altering the arrangements, and this freedom is especially valuable when it is required to transfer the traffic of the station from one line to another, diagonally at the shortest possible intervals; (2) getting rid of annoyance of snow lodging in the valleys; and (3) the grander architectural effect of the structure, whether trussed or arched. The stability of an arched roof increases with its weight and size. It may, however, be generally accepted, as stated by Mr. Matheson in his useful and practical book entitled 'Works in Iron,' that an arched roof usually costs more than a trussed roof if the expense of the abutments be included. But if, by the position or arrangement of the building, abutments already exist, or if for other reasons they have to be provided, then an arched roof may be better and cheaper than a trussed roof.

It is evident that, if strength alone be considered, the proper form of a roof is that which puts the whole in equilibrium, so that it would stand in that shape, supposing all the joints to be flexible. Any departure from this form renders the component parts subject to strain, and bracing is necessary to be introduced to maintain the form adopted. The circle is the curve of equilibrium for a uniform normal pressure, but the parabola is the curve of equilibrium for a uniformly distributed vertical load all over the span. The parabola has also a slight advantage over the circular rib in the event of unequal loading; but, as the rise of the arch is diminished, the circular and parabolic curves come so close together as practically to coincide.

The plate or solid type of arch has been largely used for roofs of comparatively small span. Examples of this form can be seen at the stations of the Metropolitan Railway, the largest span of which is 90 feet, at High Street, Kensington. The underground stations being in a cutting, a ready-made abutment exists to take the thrust of the arch, and little or no transverse bracing is needed.

The principals of the roof over the Aquarium, Westminster, resemble those at the Crystal Palace, Sydenham. They throw

a very small horizontal thrust upon their supports, being constructed with a sufficient depth at the crown to act as a girder. The ribs are semicircular in form (see diagram No. 28), having a radius of outer side, or back of rib, equal to 40 feet 4 inches, and are placed 20 feet apart, with two intermediate ribs in each bay, supported by six lattice purlins. The main ribs are braced together in pairs, these pairs occurring at intervals of 60 feet and 40 feet. The building was designed by Mr. A. Bedborough.

The main roof over the Paddington Station of the Great Western Railway is divided into three spans (see diagram No. 29). The centre span is 102 feet 6 inches in width, measuring from centre to centre of supporting columns, and forms an arch having a clear headway of 33 feet 9 inches above the springing level. The side spans are similar in construction, and are 68 feet and 70 feet wide from centre to centre of supports, with a rise of 25 feet 3 inches above the springing level to the intrados of the arch. The columns are placed 30 feet apart, and are connected by trussed girders, which carry two arched ribs in each bay. The roof is about 700 feet long, and is divided into seven spaces between columns at each end of the station, with six spaces in the centre and two intermediate transepts about 50 feet wide. The transepts are formed by arched ribs crossing each other diagonally, and give great lateral stiffness to the roof. The girders connecting the heads of columns were also omitted at the transepts, with the original intention of constructing a traversing arrangement to convey railway carriages across the station from one line to another, without the use of a turntable. The roof is glazed on the ridge-and-furrow system, following the curve of the roof, and carried on the transverse ribs, which are braced together by nine pairs of straps in each division crossing each other diagonally, and connected with the top flange of one principal and the bottom flange of the next. The roof is closed by an ornamental screen at each end. The web of the principals has a neat design of holes punched out of the solid plates. The larger holes were made with a simple screw press, having long levers and heavy weights attached to them. This method seems to be the right way of treating wrought-iron plates, the web only remaining where it acts in a similar manner to diagonals, and in the Author's opinion produces a much better effect than when raised ornaments are used. The plan has been followed in other roofs. The Paddington roof cost 19*l.* per square, exclusive of columns and girders.

The Agricultural Hall, Islington, was designed by Mr. Frederick Peck, and built in 1862. The span of the central roof is 125 feet (see diagram No. 30), with a rise of 51 feet

above the springing level. The principals are 24 feet apart, and are connected by longitudinal trussed purlins and wind-ties; the main principals rest upon a double row of braced columns, forming a base of sufficient width to resist the thrust which is conveyed through the gallery girders to the outer walls. The roof cost 12*l.* 15*s.* per square, exclusive of erection and covering. The roof over the Coventry Market Hall, designed by Messrs. Coe and Robinson (see diagram No. 31), is in a single span of 90 feet springing from the ground, and constructed somewhat similarly to the main roof of the Agricultural Hall. The centre of the top of the arch is 45 feet above the ground, and the thrust of the arch is conveyed through a side arch to the main wall of the building. The principals are placed about 8 feet apart, and connected by trussed iron purlins.

The roof over the Middlesborough Station of the North-Eastern Railway is divided into two spans of unequal lengths. (see diagram No. 32). The main roof is 309 feet long, and is composed of principals of 76 feet 6 inches (centres) in width, formed in a pointed arch shape, having a radius to each side of 42 feet, and meeting at the top, over which is fixed an ornamental ridge, fitted with side louvres for ventilation; and at each end of the station two main ribs are placed close together to carry the screen. The main ribs of the side roof are similar in construction, with a radius of rib equal to 27 feet struck from two centres, forming a roof of 42 feet 9 inches (centres) wide; the length is 183 feet, and each span is divided longitudinally between the end walls into nine spaces by eight double columns, over which the principals of the two roofs meet. The columns are connected by spandril girders carrying two intermediate ribs in each bay; the feet of the other end of the principals rest on side walls, which also carry the remaining ribs of the single roof, and are constructed to take the thrust of the outside ribs. The roof was designed in 1876 by Mr. W. Peachey.

The main ribs of the roof over the Great Hall in the Alexandra Palace are 1 foot 10 inches deep, with a radius of 39 feet 7 inches (see diagram No. 33). They are placed 25 feet apart, and are surmounted with a braced rib giving a straight incline of rafter for the covering; the springing line is 50 feet 6 inches from the floor. The late Mr. J. Johnson was the architect.

The roof over the goods station of the Great Northern Railway at Bradford consists of arched principals of 103 feet 10 inches span placed 20 apart. The main rib is 2 feet deep all round the arch, and is formed of angle iron, with flange and

ornamental quatrefoil web plates; the intrados of the arch has a radius of 52 feet. This roof was designed by the late Mr. John Fraser, and its principal dimensions have been adopted by Mr. R. Johnson in one of the spans of the terminus station roof of the Great Northern Railway at King's Cross (see diagram No. 34). The mains ribs are connected by trussed T-iron purlins, carrying two intermediate ribs. The roof consists of two spans of 105 feet 3 inches each, and the thrust on one side is taken by a heavy wood-trussed roof over the cab-rank. The web plates of the main ribs are plain. There is no diagonal wind bracing. In the last bay at the north end the purlins are made of a stronger section than the others, and T-iron bracing is introduced to sustain the lateral thrust of the roof. The cost of the roof, including a contract for the travelling scaffold used in the erection, was about 20,000*l.*

A good description of the roofs over the Crystal Palace, Sydenham, the Crystal Palace, Amsterdam, the Derby Market Hall, and the Dublin Exhibition, was given by Mr. Wessely, in his paper on "Arched Roofs," read before this Society in March 1866, and published in the 'Transactions.' In this paper Mr. Wessely alluded to the St. Pancras Station roof, the drawings for which were at that time being prepared. This roof is the largest single span we have, being 240 feet clear at the springing line. The form differs from both the circle and the parabola, the curve of equilibrium varying but slightly from the neutral line of the arched rib adopted, so that the transverse stresses arising from the weight of the roof itself are small. The arch was made slightly pointed at the top, because it was considered that this form possessed advantages in resisting the lateral pressure of the wind. Each half of the main ribs consists of two segments of circles with radii of 57 feet and 160 feet respectively, meeting in the centre, at a height of 96 feet above the level of the platform. The section of the rib varies to some extent near the springing, the lower end of the rafter in a roof having to resist the maximum strain. The feet of the principals are each secured to an anchor plate built into the wall and strongly fastened down by four bolts 3 inches in diameter, as well as connected below the level of the rail by a $\frac{5}{8}$-inch plate, which is riveted on to the bottom flange of the wrought-iron main-floor girder of the platform. There are twenty-five of these main ribs in the roof, between which trussed purlins at every 18 feet 6 inches carry intermediate ribs. The principals are placed 29 feet 4 inches apart, and the roof is 690 feet long. The purlins help to stiffen the lower flanges of the main ribs longitudinally, and the whole is braced diagonally. The roof cost 31*l.* 10*s.* per square, and

was designed by Mr. W. H. Barlow. The St. Enoch Station, Glasgow, is covered with an arched roof of somewhat similar construction (see diagram No. 35); but here the main rib consists of a curve of five centres, struck with three radii, 40 feet at the springing, 125 feet at the middle of each side, and 90 feet carried over the centre. The clear span is 198 feet, and the rise 80 feet from the soffit of the rib to the level of the platform. The roof is 518 feet 3 inches long, divided into thirteen bays of 36 feet 10 inches, one of 24 feet 9 inches, and one of 14 feet 8 inches. The principals are 5 feet deep all round, and are secured at the foot of each rib to a base-plate, which is carried in about 13 feet under the platform, and projects externally 1 foot 9 inches from the outside of the principal, the whole being firmly anchored down by $2\frac{1}{4}$-inch bolts. The principals are connected by purlins supporting four intermediate ribs, and the whole is braced diagonally by wind-ties. The end principal is filled in to serve as a wind screen, but is arranged differently to that at St. Pancras Station. In St. Enoch's Station there is no girder across the span, but the gable is trussed and bracketed firmly to the purlins, the lower portion being curved, and rising 33 feet 9 inches above the level of the platform. The wind pressure on the screen is thus transmitted to the purlins. The station forms the terminus of the Glasgow and South-Western Railway, the consulting engineer being Mr. A. Galloway. The roof over the Central Station, Manchester, is very similar to St. Enoch's, but wider, being 210 feet clear span, with a rise from springing level to the crown of 84 feet 10 inches (see diagram No. 36). The principal is composed of five centres struck with three radii of 53 feet 3 inches, 143 feet 9 inches, and 91 feet 6 inches, respectively. The principals are 35 feet apart, dividing the roof into sixteen bays, and the feet of the principals are anchored down to masonry foundations. There are four intermediate ribs, except in the end bays, where an additional main rib is substituted for the last intermediate rib, and the gable screen is made more like St. Pancras Station than St. Enoch's Station. The principals are connected by purlins and diagonal bracing, forming wind-ties, and the whole work was designed and carried out by Mr. L. H. Moorsom, to the satisfaction of the engineers of the Midland, Great Northern, and Manchester Sheffield and Lincolnshire railways. The Drill Hall at Derby is built on a similar principle, without any direct tie, the form of the arch, together with the purlin connections and diagonal bracing, being sufficient to render the construction rigid and independent of the side walls. There are nine wrought iron ribs, 75 feet span, each 2 feet deep, placed 15 feet apart,

and the level of the crown of the arch is 30 feet above the ground. The ribs spring from the ground, the lower portion being made of cast iron, and the side walls are built in between these standards. The wind-ties are of T section, running diagonally under the roof covering from the springing of each alternate rib to the crown of the arch three bays distant, crossing the intermediate ribs at the purlin connections.

The York Station belonging to the North-Eastern Railway (see diagram No. 37) is 234 feet in width between side walls, and is divided into four spans consisting of two arches of 55 feet span, having a rise of 21 feet above the springing level, one arch of 81 feet span with a rise of 27 feet, and another of 43 feet span with a rise of 16 feet 6 inches, meeting over columns placed 30 feet apart, the columns being connected by spandrel girders which carry two intermediate ribs similar in construction to the main ribs, placed 10 feet apart, there being no secondary ribs employed. The upper portion of the roof is glazed on the ridge-and-furrow system, carried on stiffeners placed between and attached to the principals, the lower portion being connected by purlins carrying the covering. The length of the roof is 795 feet. The roof is built on a curve in plan, the centre line of the main roof of 81 feet span having a radius of 1131 feet 6 inches, or about $17\frac{1}{7}$ chains. The cost of the ironwork in the roof and foundations was about 56,000*l.*, or about 30*l.* 2*s.* per square. The Sunderland Station belonging to the North-Eastern Railway is covered with a roof constructed of principals similar to those in York Station, but the glazing is differently arranged. The principals are arched ribs of 95 feet span, with a clear headway in the centre of 45 feet 6 inches above the rail level. There are 48 ribs placed 10 feet apart and connected by purlins. The ridge is raised about 9 feet 6 inches above the bottom flange of the arch at the crown to carry the rafters which run down on each side in a straight line to the gutters resting on the side walls, which are raised at the abutments to meet them. The upper portion is glazed, and curved glazing is thus avoided. The outside lower portion is slated, while the interior view shows curved boarding carried on the main ribs.

The best method of glazing is much open to argument. The ridge-and-furrow system admits of easy access for repairs, but it is evident that where the ridge and furrow follows the curve or pitch of the roof, one side of the sash-bar suffers more from the weather than the other, destroying the putty, whereas when the sash bars are parallel to the main ribs the water runs off uninterruptedly. When putty is used it should have tallow mixed with it, as in the "thermo-plastic putty" manufactured by

Sir W. A. Rose and Co., of Upper Thames Street, which, with due care in preparation, is found to harden in a few hours after it is used; but, when exposed to solar heat, sufficient to cause the expansion of the glass and metal, becomes plastic, and on cooling again returns to its original firmness. Where ordinary putty is used for glazing in exposed situations, fractures and leakages are sure to occur, and it is the wisest plan to avoid the use of putty altogether. Several methods for glazing without putty have been proposed. The plan patented by the late Mr. W. E. Rendle, who was the originator of the system, consists in constructing the sash bar in such a manner that any water finding its way through is immediately carried along the inside of the bar on to the outside of the square below, and so off the roof (see diagram No. 39). Thus with a moderately steep incline of roof there is no drip either from condensation or water driven in during violent gales of wind, and the glass having full play in every direction is free from the effects of contraction and expansion in the framework of the roof produced by variations of temperature. Patent metallic bars are employed, which are more durable than ordinary sash bars; and curved roofs can be glazed by this method with straight glass. The system has been largely adopted in several roofs, both of small and great dimensions.

A second system in use possessing some merit is that patented by Mr. J. Watson, of Torquay, in which the sash-bars do not project above the surface of the glass; but at convenient distances, or over the principals of the roof, timbers are laid in a direction parallel with the sash bars, and made to project above the surface of the glass so as to form supports for planks in case of necessary repair. The Winter Garden at Torquay (see diagram No. 40), designed by Mr. Max-am-Ende, is glazed on this system. It was erected in 1880, and consists of a central pavilion 60 feet square, with two transepts serving as entrance halls to the pavilion, and two wings, each 96 feet long, roofed over with principals of 60 feet span placed 12 feet apart, and formed of lattice girders strengthened with elliptical wrought-iron arches having cast ornamental spandrels, the whole being connected together to act as an arch. Each wing and transept terminates in a gable constructed of cast-iron framework. The slope of the roof is 1 in 2, and Z-shaped purlins formed of angle irons are placed 3 feet apart in plan, to which are fixed wooden purlins grooved on top, the grooves containing small zinc gutters. The glass is laid without lap lengthways, a clear space of $\frac{1}{8}$-inch being left upon the sash bars, while cross-ways the usual lap over the purlins is allowed. The corner of the four panes meeting at the intersection of the zinc gutters with

the laps are held down by a galvanised bolt and indiarubber washer. The patent bars in Messrs. Shelley and Co's system are of chilled cast iron, with a thin slip of vulcanite running the whole length of the bar, on which the glass rests. After the glass has been fixed in place, it is caulked along the top between the upper surface of the glass and the upper surface of the bar by a small roll or cord of vulcanite, with the object of rendering the whole both elastic and weather tight. Provision is made for carrying off condensed moisture in the grooves formed in the bars, and the lower end of each bar has a shoulder cast on it to receive the end of the lower portion of the glass sheet. The British Patent Glazing Company employ an iron bar of an inverted T section, but having the cross web made in a U shape, forming a channel in the bar or astragal for conducting moisture to the outside. The bars are fixed at convenient distances, and are enveloped in either lead, copper, or soft ductile metal, the top only being uncovered. The glass is laid on the soft metal, which acts as a cushion, and is folded down over the glazing for protection at its edges.

Another method of glazing without putty has been patented by Mr. T. W. Helliwell, of Brighouse, Yorkshire, and possesses many advantages deserving our attention. The patent is applicable both to the bar and the clip system, and the glass is made to fit close all round each square, so that there is no rattle in high wind; while the glass also receives sufficient support at the sides to be adapted to steep slopes (see diagram No. 41). No air is admitted except such as is provided for by special ventilating arrangements in the construction of the roof, which is the only true way to obtain proper ventilation. The roof over the Hide and Skin Market, Manchester, designed by Mr. F. H. Oldham, is glazed upon this system. The main rafters consist of circular ribs, 90 feet span, glazed with straight glass (see diagram No. 42). The roof is supported on columns and girders, and is ventilated by louvre standards carrying the ridge at the crown of the arch, the height of the ridge being 66 feet 4 inches above the floor.

Whatever system of glazing is adopted, a glazier's tool should never be used in the construction of a roof, as it is easy to ascertain the usual sizes manufactured, and work them in accordingly.

In the erection of roofs, it is necessary to take care not to create an initial strain upon the various portions greater than they are calculated to bear, and this precaution is especially necessary to observe with purlins. It is also essential in all riveted work to observe that the rivet holes are carefully marked and accurately punched or drilled, as in the narrow

bar usually employed in roof constructions, the stability of the structure is likely to become endangered by errors of workmanship.

The roof over the reading-room at the British Museum consists of a dome 140 feet in diameter, formed of twenty iron ribs springing from the base and united at the top by a circular ring surmounted by a lantern 40 feet in diameter. The main ribs, 106 feet in height, are filled in with brick arches, and are supported upon twenty iron piers built into brickwork, each having a bearing surface of 10 square feet, including the casing, or 200 feet in all. The form of the roof was the original idea of Mr.—afterwards Sir—Anthony Panizzi, then principal librarian of the British Museum; the details being worked out by the late Mr. Sydney Smirke, the architect to the trustees, who was assisted in his design by the late Mr. Fielder. The excellent ventilating arangements were carried out on Haydon's system, and the building was completed in 1857.

The roof over the Albert Hall is dome shaped (see diagram No. 43). The plan of the building is nearly a true ellipse, and the span of the roof is 219 feet 4 inches by 185 feet 4 inches. The principle adopted has been the construction of a continuous wrought-iron kerb resting on the top of the wall about 120 feet high from the level of the Kensington Road. This kerb may best be described as a flanged girder laid down on its side, upon which cast-iron shoes are secured by keys, from which the main curved ribs, thirty in number, spring, and in the centre of the roof another rigid kerb has been formed, to which are fastened the top extremities of the main ribs. The top of the lantern surmounting the roof is about 150 feet above the floor level. The ribs radiate from the centre of the figure, and the ironwork is so arranged that the curved principals are capable of carrying their own weight, together with the weight of seven rows of purlins, between them and the rafters of the roof and ceiling. The thrust thus produced on the main ribs is taken by the curved ring forming the wall plate, while the strains on these ribs can be adjusted by means of wedges between the wall-plate and the foot of each rib, by the slackening or tightening of which the whole of the outward thrust is brought to bear upon these curved ties, resting on the wall. The top flange of the rib acting as an arch communicates the strains produced under every variety of loading, pressure of wind, snow, &c. The wall-plate and ribs are retained in their position by means of the curved ties in the principals and bracing. The engineers for this roof were Mr. J. W. Grover and Mr. R. M. Ordish, the main building being designed by Colonel Scott.

The roof over the Winter Garden of the Leeds Infirmary,

erected in 1868 (see diagram No. 44), presents the appearance of being constructed on the principle of an arch, but is, strictly speaking, on the principle of a dome. The infirmary walls surrounding the Winter Garden do not sustain any portion of the outward thrust. The internal dimensions of this structure are 151 feet by 63 feet 6 inches. The main roof is carried by the four corner rafters or hip ribs, which, having thus to perform the chief portion of the work, are constructed stronger than the ordinary ribs. The roof is carried on twelve columns 32 feet high by 24 feet 10 inches apart, six on each side of the building, leaving a space of 37 feet 3 inches between the rows, and an aisle on each side 13 feet $1\frac{1}{2}$ inches wide. From these columns spring ornamental spandrils to a lower frame of lattice girders connecting the tops of the columns firmly together, and forming a rectangle in plan 124 feet 2 inches by 37 feet 3 inches. At each column similar spandrils to those forming the arches between the columns are placed over the side aisles, and are surmounted by cast-iron rafters with perforated webs inclined at an angle of 30° from the brick wall of the infirmary to the level of the top of the columns. The main arched ribs are also of cast iron with perforated webs, and are bolted to this bottom frame of lattice girders, and at the top to a similar rectangular frame 99 feet 4 inches by 12 feet 5 inches. This top frame is braced by cross pieces of cast iron 12 feet 5 inches apart, and is thus rendered exceedingly rigid. The weight of the upper frame, as well as the weight of the greater part of the lower roof, is transmitted to the corner ribs, which, in return, transmit a horizontal thrust upon the upper frame. The lower frame, acting as a tie, has now to receive this horizontal strain on the bottom of the ribs. The load on the intermediate ribs, although producing no outward thrust, is sustained partly by the corner ribs, partly by the upper and lower lattice girders, and partly by the intermediate columns. Both tiers of girders are 5 feet deep, and the vertical distance between them is about 15 feet 2 inches. There are two rows of cast-iron purlins connecting the main ribs, and a single row between the aisle rafters half-way between their extremities. Two rows of moulded cast-iron gutters are fixed at the base of the arch-pieces or spandrils at their junction with the lower girders, and also above the aisle rafters against the brickwork forming the walls of the central hall. The summit of the ridge-piece is 60 feet $6\frac{1}{4}$ inches above the floor level. Exclusive of glazing, the cost of this hall was about 31*l*. 6*s*. per square. The whole of the construction of this iron building was designed by Mr. R. M. Ordish, and approved by the late Professor G. Gilbert Scott, the architect of the infirmary building.

Generally speaking, the hips of a roof over a rectangular area are of special construction, but by making the ribs spring diagonally over the space to be covered and at equal distances apart, they will by their intersection divide the entire central area into equal squares, and thus make the hip ends the same as the sides and similar all round the roof. This plan was adopted in the building of a kiosk for India made entirely of cast iron. The ribs were supported on columns placed 10 feet apart round the exterior of the structure, which was 80 feet long, 40 feet wide, and 42 feet high in the centre. The base of each column was attached by bolts to a girder running inwards for a distance of 10 feet beneath the floor level, thus enabling each column to resist the tendency of turning, under the influence of strain produced by the load on the roof. A considerable amount of ornamental effect was aimed at, and secured, in the design. Another good example of cast ironwork as adapted to roofing is to be found in the Santiago Market, designed by Mr. C. H. Driver, architect, and Mr. Edward Woods, civil engineer. The building occupies a rectangular space, surrounded by a low corridor, which separates it from a one-storied building. The market is divided into nine squares, over which are constructed separate roofs carried on columns and girders. The central roof is the highest, and is surmounted by a dome. The roofs over the four squares at the angles are less in height than the central one, and the roofs over the middle squares along each side are at a lower level again. Each roof is hipped each way, and their varying height enables their louvred faces to be well exposed to the air. The new Central Fruit and Vegetable Market now in course of construction, designed by Mr. Horace Jones, the City architect, is situate at the junction of Charterhouse Street with Farringdon Road. This site is likewise divided into nine squares by sixteen columns placed at the angles of the squares, and connected at the top by girders which carry the roofing. The roofs over the outside squares are of timber, with clear spans of 47 feet 6 inches and 56 feet respectively. The girders forming the centre square are united at the corners by girders of the same depth, 22 feet in length, so as to form an octagon in plan, measuring 25 feet parallel to the columns. The roof consists of eight wrought-iron ribs springing from the angles with a rise of 22 feet 6 inches, and united at the top by an octagonal ring measuring 10 feet 3 inches, parallel to the line of columns, and 9 feet at the angles. Wrought-iron purlins are placed round the dome, the construction forming a rigid skeleton of ironwork, which is filled in with ornamental woodwork, and fitted with eight large glass louvres, affording an ample amount of ventilation, so essen-

tial for a market of this description, while at the same time the building is well lighted without admitting the glare of the sun.

The area occupied by the various lines and platforms in the terminus station of the Great Eastern Railway at Liverpool Street (see diagram No. 45) is covered with a roof in four spans, the two central ones being 109 feet each, and the side spans 46 feet 4 inches and 44 feet 8 inches respectively. The central spans each consist of two cantilevers supporting a girder similar to the truss shown in No. 8 (see diagram), but with the diagonals placed in the opposite direction, that is, with their top ends pointing towards the centre of the span. The principals over each span are secured to each other over the supports, and form a continuous girder anchored down at the ends by the arches forming the wall, as well as by bolts built into the brickwork. Cast-iron columns form the supports at the junction of the roofs, and are placed double in the centre at the meeting of the two main spans on account of the extra weight to be sustained at this point compared with that at the junction with the side spans. The centre columns are placed 5 feet apart transversely, so as to reduce the strains on one span caused by unequal loading on the other. The columns act as rain-water pipes to drain the roof, and are placed 30 feet apart under each principal longitudinally. The main ribs are connected by trussed purlins divided into three bays, and glazed upon the ridge-and-furrow system, resting upon the diagonal bars of the truss, and the whole roof is further stiffened by special spandril castings springing from column to column between the principals. A transept is formed in one part of the roof where it was required to place the columns as far apart as possible, and diagonal ribs intersecting each other, similar in construction to the transverse principals, are here introduced, together with a special principal between the spans, by which means a clear space of 90 feet between the columns longitudinally is here obtained, and great lateral stiffness given to the whole structure. The roof was designed by the late Mr. Edward Wilson. The roof over the Aldgate Station of the Metropolitan Railway is constructed of principals somewhat similar in construction to the centre span of the roof last described, but wholly of wrought iron. The principals divide the roof into six bays or spaces of 18 feet each, and are 82 feet $4\frac{1}{2}$ inches span. The roof over the new railway station at Brighton is to be divided into four spans and supported on columns. The centre line of the station will have a radius on plan of 1148 feet, and the spans will taper from one end to the other. The principal spans will resemble those last described, and will be formed of upper straight rafters having a slope of 1 in 2, with a lower curved rib and lattice web. One

span will taper from 106 feet to 117 feet, the 106 feet span having a rise of 24 feet from the intrados of the arch to the springing level, and the other main span will taper from 98 feet to 75 feet, the 98 feet span having a rise of 23 feet above the springing level to the intrados of the arch. The principals will be placed 25 feet apart, and the supporting columns connected by spandril girders carrying three intermediate ribs in each bay. The main principals will be bolted firmly together and attached rigidly to a raised portion of the column, both in the centre of the station and also to the side spans, which will vary in width, their maximum dimensions being 46 feet on one side and 38 feet on the other. The detail drawings for this work are now being prepared by Mr. Henry E. Wallis, subject to the approval of Mr. F. D. Bannister, the engineer to the London Brighton and South Coast Railway Company.

In the Canterbury Music Hall, Westminster Bridge Road, novel arrangements have been adopted to insure free circulation of air. The open central space over the pit is 36 feet long by 18 feet wide, fitted with a special movable covering, which slides laterally in one piece (see diagram No. 46). The side walls of the building are connected by main girders united by transverse girders, which are likewise attached to other girders running at right angles to them and parallel to the main girders, the whole framework being firmly braced together by diagonal ties, forming a very rigid and strong construction. The sliding portion rests on a continuous line of rails 37 feet apart, fixed to longitudinal bearers attached to all the transverse girders. Such an arrangement enables the interior to be speedily freed from all vitiated air, and would prove of advantage in the event of fire, enabling firemen the more readily to direct the hose to the parts most affected. The plan was the invention of Mr. Robert Edwin Villiers, the late manager (patent, A.D. 1877, No. 4581). The work was completed in 1876. In the hall of the Circus at Paris the same idea has been carried out on a larger scale (see diagram No. 47). The central space over the arena is surmounted with a special movable covering, 177 feet long by 57 feet wide, which divides into two equal parts longitudinally, each resting on wheels, so as to be pulled aside right and left, when the weather permits, on outside girders, and thus completely to disappear from the audience inside. The fixed roofing which surrounds the space closed by the sliding portion is supported on columns. The hall was built in 1877, under the direction of Mr. E. Lantrac, the engineer to the Circus Company, by whom the work was designed.

Another example of an opening roof exists in the Royal Observatory of Vienna, designed by Mr. F. Fillner, architect. In this case a dome (see diagram No. 48) 45 feet in diameter is constructed to revolve, and by means of special gearing a clear opening provided in the roof by raising up a shutter one side and lowering it the other. The dome is formed of two thin shells of steel plates, varying in thickness from No. 16 to No. 18 B.W.G., riveted on the inside and outside of light steel plate girders 9 inches deep at the crown and 18 inches at the base, which is stiffened sufficiently to bear the varying strains as the dome revolves without producing outward thrust. The revolving arrangements were designed by Mr. Howard Grubb, Honorary Master of Engineering in the University of Dublin. They consist of twenty sets of three rollers fastened rigidly together, and connected neither to the dome nor the walls. The foot-plate of the dome is made with a projecting rib, which travels on the centre roller, without bearing on the side rollers, and the side rollers travel on a special bed-plate secured to the wall, and provided with two projecting ribs, which serve as rails to carry them. The faces of these upper and lower projecting ribs, on which the rollers revolve, are not parallel, but are planed so as to converge accurately to the centre of the dome. The rollers are turned true to fit these ribs, and the inner roller is grooved to direct them in turning round. Sliding friction is thus practically reduced to zero, and a kind of "live ring" is formed moving at half the speed of the dome. The rollers are placed at a sufficient distance apart to maintain lateral stiffness in the ring, while the dome is prevented from slipping by an independent set of guide rollers, supported on brackets descending from the dome, and bearing against a ring made to slide true round the cast-iron wall-plate. Any alteration of form in the dome can be provided for without interfering with the supporting system, by adjusting the lateral rollers, which always have a true circle to play against so long as the wall holds, and the construction of the dome commends itself as giving maximum stiffness with a minimum amount of material, in addition to the advantage of the temperature inside when the dome is closed being uniform with the outside.

There are occasions in an engineer's practice when roofs have to be lifted while the traffic beneath must go on uninterruptedly. Such was the case at the London and North-Western Railway Company's Euston Station, which, owing to increased traffic, was found deficient in ventilation, and was raised about 6 feet by the aid of some forty powerful screw-jacks. Some of the jacks were afterwards used in lifting the Great Northern Railway Company's eastern goods' shed roof.

All iron exposed to the air is more or less sensitive to corrosion and consequent decay, which may be delayed by galvanising the iron, or covering it with a thin coating of zinc. Another plan, known as Professor Barff's method, consists in placing wrought iron and steel under the influence of superheated steam at a sufficiently high temperature to decompose the steam and allow its oxygen to attack the iron or steel, whereby a hard coating of magnetic oxide is formed upon its surface, which is less affected by atmospheric conditions than any other covering. The working of the process has been improved upon in the Bower-Barff method, by means of which not only wrought iron and steel but cast iron can all be treated in the same furnace and rendered rustless with equal permanency and expedition. The process is of recent introduction, but gives fair promise of success, being simple in application and comparatively inexpensive. The iron is placed in a firebrick chamber, connected with which is a set of gas producers; but before admitting the gas it is led along passages and mixed with air in a highly heated condition, forming carbonic acid, which, with a small quantity of free air, is allowed to enter the chamber and become partially divested of oxygen by contact with the heated material. It is necessary to limit the quantity of air admitted, as an excess causes a film of the sesquioxide of iron (Fe_2O_3) to be formed over the coating of the magnetic oxide (Fe_3O_4). The air is heated in the chamber by passing over a fireclay regenerator, both for the purpose of combustion and also for oxidation. The sesquioxide of iron can be reduced by closing the air valve and letting carbonic oxide into the chamber. Rusty iron may be similarly treated. Anti-corrosive paints are less efficacious, and paint only serves for purposes of decoration and subsequent preservation. As an able paper on the use of paint as an engineering material was read before this Society by Mr. Ernest Spon on May 3, 1875, and is published in the 'Transactions,' the Author will not now dwell further on this point beyond remarking that he believes oiling to be a much better protection from the effects of the weather or the action of steam than painting, but care is needed properly to clean off the black scale or oxide formed upon the iron by contact with the air immediately after leaving the rolls. In Holland great attention is paid to these details, the specifications of the engineers minutely describing how the iron is to be treated before the oil and paint are applied. After being properly cut, punched, or otherwise finished off in the shops, each piece before being fastened to any other piece is made quite free from rust and scales by immersion in a bath of dilute muriatic acid, and kept there as long as the inspecting

engineer thinks proper. It is then lifted out by means of iron hooks and brushed with water, which removes all the black scale. Immediately afterwards it is immersed in a bath of fresh limewater, and then placed in a bath of boiling water, where it must remain till it is about as hot as the water. The water is renewed directly any traces of acid are discovered in the water bath. After being thus washed, the iron is removed from the hot-water bath and allowed to dry, but before becoming quite dry, while still warm it is besmeared abundantly with hot linseed oil, and then receives the first coat of paint. All rivet heads are similarly covered with hot linseed oil and painted over after the plates or other pieces are riveted up. A second coat of paint is given to the iron before it is placed in contact with other pieces of different material, and while all parts are accessible to the painter's brush, care being taken that the pieces so painted are perfectly dry, and that the weather is not damp at the time the second coat of paint is applied. The paint used consists of lead or iron minium well mixed with boiled linseed oil. Iron minium, consisting of iron oxide with a small proportion of clay and water, is cheaper and more used than lead minium.

The construction of iron roofs is a question in which the combined experience of civil and mechanical engineers, manufacturers, and contractors can scarcely fail to prove valuable, and the Author has therefore selected this subject, hoping to have a discussion which will fully redeem all the shortcomings of his remarks upon this important subject.

Too much importance must not be laid upon the cost quoted for different roofs, as they were erected at different times, and the price of material is constantly varying. Even with a uniform price for iron, comparisons cannot be usefully made, unless every particular was included. The Author has, however, stated the price where possible, as one of the questions which engineers are compelled to enter into is the financial result of their work.

In conclusion, the Author begs to acknowledge the courtesy with which many engineers have placed at his disposal the information from which this paper has been compiled.

November 7th, 1881.

CHARLES HORSLEY, President, in the Chair.

IRON ROOFS.

By Arthur T. Walmisley, A.K.C.

DISCUSSION.

Mr. Perry F. Nursey said that among the numerous roofs described by Mr. Walmisley, in the interesting and pains-taking paper he read at the last meeting, he referred to that at the St. Pancras Station of the Midland Railway, and stated that it was the largest single span we had, namely, 240 feet, and it was generally understood to be the largest span in the world. Up to the time of the St. Pancras roof being designed, the largest roof supposed to have ever been executed in one span was that of the Imperial Riding House at Moscow, which was built in 1790. The span was 235 feet, and the ambition to produce the largest span roof in the world had something to do in deciding the span of the St. Pancras roof, which was 240 feet, or 5 feet more than the Moscow roof. In one account of that roof, the principal feature was stated to be an arched beam, the ends of which were kept from spreading by a tie-beam, the two being firmly connected by suspension pieces and diagonal braces. The arched beam was said to be formed of three thicknesses of timber, notched out to prevent their sliding on each other. That method, however, was objectionable, on account of the danger of the splitting of the timber under a considerable strain. In a work on carpentry by Colonel C. R. Emy, a French military engineer, some details of the Moscow Riding School roof were given, which showed it to be constructed on a totally different principle. It was there shown as a laminated, arched rib, double, and braced at the springing, and upwards for about one-sixth of the whole rib, but without any tie-beam, suspension members, or diagonal bracing, beyond that at the springing, which he had just mentioned. That principle of a laminated, arched rib was devised by Colonel Emy in 1817, and was applied by him in 1825 in the erection of a roof of 65 feet span at Marac, near Bayonne. It would thus be seen that these two descriptions of the Moscow roof by no means agreed, but that

was not the only element of discord which he had experienced in endeavouring to find out what the principle of the Moscow roof really was. Turning to Gwilt's 'Encyclopædia of Architecture,' he found, at page 612, a very brief notice of the Moscow roof which was only stated to have been "projected," and that brief description was supplemented by a statement that Cresy in his 'Civil Engineering' asserted that the Moscow roof was never erected. Cresy gave the span as 220 feet. It would therefore be interesting to the meeting if any member could state from personal knowledge, first, whether there was a riding house in Moscow; secondly, whether it had a roof at all; and, if so, thirdly, upon what principle it was constructed, and of what span.

Turning to the question of roofs generally, there was one important point which should receive careful attention in their design; and that was their pitch or slope. That depended on the climate against which they were to serve as a protection, and the nature of the covering. In hot countries, where rain was infrequent and the temperature high, the roofs were comparatively flat, whilst in cold countries, with a moist atmosphere, roofs had a higher pitch. Thus, in the southern parts of Europe the roofs were very flat, whilst in its northern parts they had a considerable elevation given to then. Gwilt, in his work already referred to, gave a tabular statement of the pitch for roofs as applicable to fifty-two European cities, the roofs being covered in various ways. For London, the pitch of a roof covered with hollow tiles, as in France, was given as 27° 24′; covered with Roman tiles, 30° 24′; with slates, 33° 24′; and with plain tiles, 35° 24′. The table had been compiled according to certain stated laws deduced from the influences and variations of climate, and a comparison of it which was there made with ancient buildings gave a remarkable corroboration of its value. These rules, of course, applied only to angular roofs, and not to the curved roofs of modern construction. In the examples of angular roofs given by the Author, however, the highest pitch appeared to be considerably less than the actual pitch given by Gwilt. The fact of the covering being of metal and glass probably influenced the angle of pitch, and accounted for its lowness. At the same time, it might be worth while to consider whether a somewhat higher pitch would not conduce to a more rapid delivery of rain and snow, a more speedy drying of the covering, and consequently a more lengthy existence.

Mr. THOMAS GILLOTT remarked that the Author's paper was mainly a description of existing roofs, but as such would be a most complete and valuable record of structures erected up to this date. The remarks he had to submit might not appear to be

altogether within the limits of the paper the Author had taken so much trouble to prepare; but he did not notice that the Author had specially selected any particular type of truss as being the most economical to construct, and although, speaking generally, all the small roofs have triangular trusses, and the large roofs have a curved outline, no particular span appears to be indicated as the point of departure from the straight rafter to the curved rib or truss, or whether such departure is desirable when a certain span is reached, and economy of construction is the motive for it.

Previous investigations of his own* were made to determine the most economical secondary trussing for a plain triangular roof principal, and also the best pitch of rafter to employ. The method adopted was to sum the products of the lengths of the various members multiplied by the strain on them, for each kind of truss; and by comparing the theoretical weights of seven different types to determine that which could be made with the least material. Thus supposing the principal to be of wrought iron, and the bars in tension and compression strained respectively to 4 tons and $1\frac{1}{4}$ tons per square inch, the theoretical weights of principals 60 feet span and 12 feet rise, to sustain an equally distributed load of 8 tons, would be:—

	lbs.
Types 6 and 9, with bracing to form four divisions in each main rafter	1978
With vertical struts and ties sloping from the foot of each strut upwards (towards the centre)	2073
Type No. 10	2091
Type No. 2 (with three divisions in rafter)	1990

He agreed with the Author in selecting No. 9 in preference to No. 6; on account of the shorter struts, and the less expensive joints with the former.

As to the best pitch for a roof, it is evident that, with similar trusses, a more expensive covering ought, from motives of economy only, to be placed at a flatter pitch than less expensive materials; and that, theoretically, a deep truss can be constructed with less iron than one with less rise in proportion to the span. In the papers referred to, the angle of the rafters with the horizontal was shown to give a roof of minimum cost when determined by the following equation:—

$$\frac{dy}{d\theta} = 2c\ (aq + bq_1)\ \tan{}^4\theta + e\ \tan{}^3\theta + c\ (aq + bq_1)\ \tan{}^2\theta - c\ (a + b)\ p = 0$$

* See 'Trans. Leeds Association of Engineers, 1871–2,' and Paper read before the British Association, partly published in *The Engineer*, Aug. 11, 1871.

in which y = total cost, θ = angle of rafter, c = half-span, e = cost per square unit of covering, a and b = the respective costs of ties and struts to transmit an unit of strain (say one ton) through an unit of length (say one foot); p, q and q_1 are factors depending for their values on the weight per square unit, and the number of divisions in the rafter formed by the secondary trussing.

For instance, if the principal be of wrought iron, the ties made of flat bars and in their manufactured state worth 12*s.* per cwt., which, with allowances of 50 per cent. for punching, and 70 per cent. for joints *on the nett material,* strained to 4 tons per square inch, makes the value of $a = 2 \cdot 358d.$, and the struts at 12*s.* 6*d.* per cwt., sustaining a gross average strain of $1\frac{1}{4}$ tons per square inch, making $b = 3d.$ Let the covering be of slates on timber laths, and purlins worth 6*d.* per square foot, $= e$, and the weight 15 cwt. per 100 square feet. Then, for types 6 and 9, the most economical pitches will be:—

For 20 feet span, two divisions in rafter, rise = 3·54 feet, or 19° 31′ inclination.
For 60 feet „ four „ „ „ = 13·95 feet, or 24° 57′ „

But if the covering had been worth 9*d.* per square foot, the angles of inclination to give the minimum cost would have been 17° 23′ for the 20 feet span, and 22° 53′ for the 60 feet span. In both cases the main tie is assumed to be horizontal.

For all roofs up to 70 feet span he had preferred flat riveted tie-bars to forged ends welded on to round rods, or screwed ends. The losses due to punching average about 25 per cent., varying from $37\frac{1}{2}$ per cent. in the small bars to 15 per cent. in large ones. The loss of strength by screwing solid bars, taking the usual reduction of area by Whitworth threads, is as under:—

Diameter .. inches	$\frac{1}{2}$	$\frac{5}{8}$ & $\frac{3}{4}$	$\frac{7}{8}$ & 1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$
Loss per cent.	30	25	$22\frac{1}{2}$	20	18	20	16

His own experiments on the strength of welded joints have shown that with the highest class of wrought iron, capable of sustaining $23\frac{1}{2}$ tons per square inch, the tensile strength of the same iron welded (six experiments) varied from 15 to $19\frac{1}{2}$ tons per square inch, and an average loss by welding of 25 per cent. And in the case of mild steel, capable of bearing 27 tons per square inch with an elongation of 26 per cent. in 10 inches, the strength of the welded joints varied from 16 to 23 tons per square inch; the difficulty of welding steel, even of this quality, without injury, is such that he certainly could not recommend the practice; as the limit between a heat sufficient for welding and a heat that will "burn" is so narrow as to make the strength of welded steel a matter of great uncertainty.

He did not see that the Author had dealt with methods of manufacture, but it appears to him that the subject is one deserving of attention. Nor is there special reference to the employment of cast-iron struts in combination with wrought-iron ties, a practice which, on account of having little merit in design, and often requiring the replacement of material broken during erection or transit, seemed to him worth mentioning for the sake of condemning; and as the various sections suitable for compression bars are made of considerable external dimensions, with small thickness, there is no economy at the present time in using cast iron for roof struts.

Mr. LIGHT said that Mr. Gillott, in his remarks, had assumed the tie-rod to be horizontal, whereas in practice it never was so, and that would alter his angle most materially, so that it could in no sense be compared with the others that had been given. It seemed practically almost impossible to obtain a fair comparison of prices for roofs, but it would be a very valuable guide to engineers if such particulars of actual cost could be obtained as would render it possible to make a comparison between the cost of the main items, such as framing and covering, and columns (if any) in various roofs, stating at the same time the current prices of ironwork. Some idea could thus be formed of the relative cost of different designs. Of course in some cases roofs were designed for pure economy, with the plainest and simplest work to cover a given space; in other cases, ornament entered more or less into the requirements of the construction, and these considerations largely affect the cost. The Author had called attention to a point which was evidently of more importance than might be thought beforehand, viz. the side which, relatively to the prevailing wind, ought to be the fixed side in the case of roofs which were fixed on one side only, and were sliding on the other. The Author also remarked that roller frames might lessen the rocking motion, but would not prevent it. Probably they all knew pretty well by this time that roller frames practically failed to act in nine cases out of ten. That being the case, a planed face would do all that the roller could do, and would give other advantages besides. If there was any possibility of a considerable deflection, it would, he thought, be certainly desirable to adopt the system which the author mentioned as having been adopted in one or two cases—that of setting the bearing-plates upon a rocking frame, so that they might accommodate themselves entirely to any action of the roof, however slight, and that there might be no danger whatever of an excess of pressure on the forward edge.

There was one point which, as it appeared to him, designers of roofs had in a very great measure ignored. They had in

many cases attained great success as regards the interior appearance, but they seemed to forget that many of the large roofs are seen, and very prominently too, from the outside also. For example, however excellent might be the roofs of the Charing Cross and Cannon Street Stations as engineering works, nobody could call them beautiful objects as regarded their architectural appearance from the outside. In that respect it certainly seemed as if the more recent practice of using what might be called secondary roofs, as in the case of the new stations at Glasgow, presented, besides other merits which they were said to possess, the advantage of breaking up the lines of the roof as seen from the outside, and affording something more agreeable to the eye than the enormous boiler-like structures to which he had alluded. One great merit of the Author's paper consisted in its having accumulated the particulars of a most unusually large number of examples of roofs of various designs and general characteristics. It would considerably add to the usefulness of the paper, when it appeared in the 'Transactions,' if the Author would append to it a table classifying under the numbers he has assigned to his diagrams the names and spans of all the roofs which belong to each particular class. An engineer, when designing a roof, could then readily ascertain what important roofs exist of that particular class which he proposes to adopt. This would be conducive to the advantage of the profession generally.

Mr. F. E. Duckham expressed the gratitude which, as an engineer, he felt for the many examples of roofs the Author had presented in his paper, and for the full descriptions he had given of them. The roofing over the Millwall Dock Grain Depôt, to which the Author referred, had now been completed by Messrs. Cutler and Sons. It covered an area of $4\frac{1}{2}$ acres; its cost, including the corrugated iron and skylights, was about 4*l.* per square. It stood upon exposed ground, the recent gale was a severe test for such a roof so placed, but no movement whatever could then be detected in any part of the structure.

The roof truss shown by diagram No. 10, omitting the unnecessary vertical tie-rod, resembled the design of a series of roofs which he had put over some sheds near Victoria Docks eighteen years ago. The work was done cheaply for a temporary purpose, and the scantling was exceptionally light; but these roofs, with their pantile covering, were yet in use and in very good condition. He had also put up some roofs with trusses resembling Fig. 2, mostly of 44 feet span, with slate coverings, on rough boards and battens, with satisfactory results.

He could not claim such intimate experience with other examples mentioned by the author. Some of them certainly

seemed to possess peculiarities which he, as an uninformed critic, might pronounce objectionable, but it should be ever borne in mind that both the design and the cost of such works depend to a very great extent upon special local circumstances. While, however, no example of work done should be absolutely condemned nor blindly repeated, the Author's paper was most valuable, containing as it did such a mass of information upon a subject of much importance to many engineers.

Mr. James M. Blair said that in reading the Author's paper in *The Engineer* he noticed a slight error with regard to the covering of the North British Station at Glasgow. The Author states that it cost 15*l.* a square, exclusive of the foundations and drainage. Now this is simply the cost of ironwork, and does not include covering. He had figured up the exact cost of the three roofs executed in Glasgow by his firm, and referred to in the Author's paper, namely, the roof over the Central Station, that over Bridge Street Station, and that over Queen Street Station. The first two of those roofs were completely covered with glass on Rendle's patent system, so that so far there is a clear comparison. The roof of the Central Station cost for iron and covering complete 28*l.* 17*s.* 6*d.* per square of 100 feet, and that of the Bridge Street Station 22*l.* 5*s.* per square. The North British roof at the Queen Street Station was covered with glass to a large extent, but not on Rendle's system. The proportion of area covered being about one half glass, one fourth of sheet lead on sarking, and one fourth of slates on sarking. The actual cost of it was 21*l.* per square. In order to compare with the others, he had calculated the cost of this roof as being covered on Rendle's system, and found it would have cost 23*l.* 3*s.* per square, so that really the North British Station has been covered at less cost per square than the others. The costs were largely influenced by special existing circumstances, such as design, price of material, and the difficulties connected with erection, which were greater in some cases than in others.

He would be happy to answer any questions, or give any further information regarding these roofs which the Members might desire.

Mr. Jabez Church said that one thing which struck him on hearing the paper read was the great difference in the cost of various roofs. He was aware that they could not exactly analyse their relative cost from these figures, but at the same time they could in a general way decide which was an expensive roof and which was a cheap one. Some of the large roofs —that over St. Pancras for instance—were certainly of an expensive type. He believed that the Author put the St. Pancras roof, which has a span of 240 feet, at 31*l.* 10*s.* a square.

Another large roof of almost the same span was that of the Central Station in Glasgow, and that was given at 14*l.* 5*s.* the square, the span being 213 feet 6 inches. The roof at the York Station, in four spans, was altogether 234 feet wide, and this the Author stated cost 30*l.* 2*s.* per square. At all events, it was a fact that a roof like that at St. Pancras must cost a great deal of money, however beautiful it might be; and it certainly was a very handsome structure, and one that any engineer might be proud of. Engineers had, however, to look at cost, inasmuch as money invested by shareholders was expected to pay a certain dividend, and the successful engineer must, as far as possible, make his work a commercial, as well as an engineering, success. No doubt large roofs at railway stations had great advantages. For instance, there were no columns in the way, and the engineer could arrange the rails and the platforms or shift their position as circumstances required. On the other hand, when an area of large span was covered with two or three roofs instead of one large one, the columns could be arranged so as to stand in the middle of the cab-ways or on the platforms, and so be out of the way of any danger that might happen from trains running off the line and into the columns, thereby endangering the roof. Mr. Light had said that engineers in designing iron roofs considered their appearance inside but were regardless of their outward effect. He (Mr. Church) thought that some of the large roofs which had been put up, however well they might look inside, certainly had anything but a handsome outward appearance. With regard to rollers for the principals of roofs, he thought that experience had certainly exploded to a very great extent the idea of their utility; for the rollers very often corroded and got set, so that when the roof expanded they entirely failed to act. Planed plates, if properly made, no doubt answered every purpose. As to wind pressure, they were told by the Author that 40 lbs. to 45 lbs. per foot was the outside strain that should be allowed for in a roof. He (Mr. Church) saw that after a recent storm the wind pressure was recorded at places as high as 57 lb. on the square foot. If that were the case, a great many roofs ought to have been blown down. He should be very glad if some gentleman learned in meteorological science would give them some idea of what he considered should be allowed for in the strain on a roof in consequence of the pressure of the wind. There was no doubt that the wind came in very curious forms. He saw after the late gale the strong part of a wall that had been blown down, while the weaker part was left standing. He could only imagine that that was the result of the wind coming upon it in the form of a corkscrew, or something like

a shot from a rifled gun; of course outside pressure ought to be provided for, but he nevertheless thought that 57 lb. on the square foot would be a very tremendous strain to provide for, and one which he should not think of adopting.

Mr. Schönheyder, after expressing his sense of the very great pains to which the Author had gone in preparing the paper and the diagrams, said that the paper would be made much more useful if it was transposed into a huge diagram, with columns containing the name of the roof, the span, the rise and the distance apart of the principals, the weight per square and the cost per square, with a further column for general remarks. This would be a very valuable arrangement for facilitating reference. The paper was entirely descriptive, and as such was valuable; it did not pretend to be a complete treatise on roofs. It would, however, have been valuable if, in addition to description, there had been some remarks made as to the strength of roofs—not necessarily complete formulæ, for these could always be obtained; but, no doubt, the author was in possession of the result of experiments as to the loads which could be borne by columns of a certain strength and length, and by T iron and cross iron of certain sections, and any information of that sort would be of immense value to those who had to do with designing roofs. One point of importance in connection with the strength of roofs, was the form of the eyes of tie-rods. The hole in the eye was usually circular, but the outside, instead of being made elliptical, with a large excess of material, especially at the crown, was frequently made circular and with an insufficient amount of material. That was a point which required careful consideration. Some remarks had been made about the corrosion of iron. The Barff process was a most valuable process for preserving ironwork of all kinds. It consisted in subjecting the iron to a red heat, and then admitting superheated steam to it while enclosed in a retort heated by a furnace. By this process the outside of the iron was changed to black magnetic oxide, which was not attacked by the atmosphere. It was his opinion that in less than ten years time every ironworks would have to adopt that process of preserving iron, and engineers, in making specifications, ought to stipulate for such a process; it was the only rational process for preserving iron. He would, in conclusion, draw the attention of the Author to the market roof he alluded to at Manchester. It appeared to be semicircular, but there did not seem to be any tie-rods. The columns could never be bolted down sufficiently to take the horizontal thrust.

Mr. Bernays said that he had had prepared a list with prices from the Author's paper, made out precisely in the way

Mr. Schönheyder had indicated, but in looking through the prices he could not make head or tail of them for the purposes of comparison. There were so many circumstances to be taken into account in the construction of different roofs that prices could not be compared. Those which had been described varied from 49*l.* 10*s.* a square, down to 6*l.* a square, to which he would add another example. Not very long ago he designed a small roof of about 42 feet span for an engine-house. It had hipped ends, and the ironwork cost, complete, 8*l.* 10*s.* per square.

Mr. Cutler added his testimony as to the great value of the paper. Several speakers had referred to the discrepancy in the relative cost of roofs detailed in the paper. In his experience much of this irregularity in price was occasioned by the sometimes disproportionate attention on the part of engineers to the amount of labour involved in the carrying out of their designs. He often found roofs and kindred structures devised in the most careful manner with the object of reducing the amount of material, but this reduction was very often accompanied by an increased cost of labour. He would venture therefore to suggest to engineers the importance of bearing this point more often in mind when they were designing ironwork. It was oftentimes of more importance, in these days of costly and untractable labour, to reduce the amount of skilled workmanship required to manufacture the structure than to lessen the amount of material itself. The extremely low cost of the roof at the Millwall Docks, to which reference had been made, had resulted mainly from the comparatively very small amount of labour which was required in its construction. He did not remember to have previously seen such a cheap roof to work out. Passing to the remarks of Mr. Gillott, no doubt a riveted joint was an excellent manner of connecting ironwork whenever it could be applied, provided that it be properly proportioned and well carried out. His firm was at this very time constructing a large roof for an important corporation. Every junction which it comprised consisting of riveted joints, the holes for which being carefully drilled, and all the parts machine fitted. The fitting and careful proportioning of the junctions of ironwork was another thing which obviously was entitled to the greatest care and attention, and in these days of very severe competition it became increasingly important that it should be insisted on.

Mr. Harley (Glasgow) said that, as an engineer and contractor, he could thoroughly sympathise with the remarks of the last speaker, in so far as good work could only be got by active superintendence on the part of the engineer. At the same

time, without going further into the question of this superintendence, or that of the rules supposed to be laid down for guidance in the covering of large areas, he should like to ask for some information with regard to the use of iron in these structures, if it was not to get a maximum of strength with a minimum of bulk? and if that was so, he thought the introduction of any material but iron must be a fault. Several railway station roofs in this country could not, strictly speaking, be called iron structures, but composite structures, in so far that wood formed a large item, such as in cross purlins, sarking, &c., as supports for glazing and slating purposes. Corrugated iron, he thought, was a good substitute for slates, and it had the merit of expanding and contracting the same in variable temperatures as the rest of the structure. As for glazing, he was partner in a firm of patentees of a system of puttyless glazing which had been referred to. In this system there was a core or astragal of rolled iron of a particular section, which got that minimum of bulk with maximum of strength aimed at in the covering of large areas, and this core or astragal was surrounded by lead as a substitute for putty. The exposed parts of the iron core were subjected to the Barff-Bower process, and thereby rendered anti-corrosive. He had heard that in the construction of a roof where the vibrations were not excessive, the Barff-Bower process would answer very well, but he did not know if it would answer to coat the iron first, and put in hot rivets, as the rise in temperature and the hammering up of the rivets might tend to detach the magnetic oxide.

Mr. Schönheyder said that in his remarks about corrosion, which was, of course, a very important point, he omitted to state that, as far as he had heard and had tried the process, it was rendered imperfect through the impurities of the iron. Wherever any silica occurred in the iron it was of course impossible to change it into magnetic oxide. Therefore the protecting of common rough iron with the Barff process was rather incomplete. But as steel was being used more and more every day we should get better protected surfaces, as steel was acted upon over the whole surface, as there were very few impurities in it. He should think that the magnetic oxide would be liable to be knocked off in the manner just stated when riveting was being done, but he did not think that the mere heat of the rivets would affect the process, for the iron had been already made nearly as hot as the rivets would be.

Mr. Gandon said that as the Barff process had been referred to, he should like to obtain a little more information about it. So far as he had had experience of it a very slight blow was sufficient to detach the magnetic oxide. The strength of a

thing must be measured by the strength of its weakest part, and a coating of magnetic oxide would be of very little use if portions of it were liable to be detached by blows. He did not wish to be understood as running down the process, for he thought that it was a most useful one if it could be made to stand ordinary usage. His experience of it, however, was that there were always weak points in the coating.

Mr. Blair said that he had tried the Barff process on some railway sleepers made of $\frac{3}{16}$-inch plate. Very little pressure made the coating come off. Clean steel plates in the form of sleepers were treated with the process, and a little pressure in a hydraulic press made the coating come off in scales, in all directions, so that this system is quite unsuitable for coating metals subjected to straining.

Mr. Nursey said that he had had opportunities during the last few years of observing both the Bower and the Barff processes alluded to by the Author at the conclusion of his paper. They were two distinct operations which were now combined under one name, Mr. Bower having bought up all Mr. Barff's patents. For some years Mr. Bower and Mr. Barff worked at the same question, and for a long time they both had very great difficulty in dealing either with wrought iron or with steel. He (Mr. Nursey) had in his possession some examples of cast iron which had been treated by both processes, and he had subjected them to various tests, but had found there was no chipping of the surface, and no exfoliation produced either by long exposure to the atmosphere and weather, or by acids or blows. But he believed that a difficulty was found in the case of wrought iron and steel, and, in fact, he believed that the Bower process was not of itself applicable to either of those materials, though it was eminently applicable to cast iron. He believed that Mr. Bower was now working out the question with a view to combining the two processes, and rendering them applicable both to wrought iron and to steel.

Mr. Walmisley, in reply, said that the remarks which had been made could not but add value to the paper. As to the riding school at Moscow, he could not tell whether it existed or not; but he had always been accustomed to accept the arched and notched form which Mr. Nursey had indicated as that of the roof of that building, supposing it to exist. With regard to calculations of strength, and questions of manufacture, it was not his object in writing the paper to go into such points. He rather hoped to elicit information from other engineers on these points. He had simply brought before them examples which he had collected for his own information and instruction. Mr. Gillott's remarks had been partly answered by Mr. Light. He

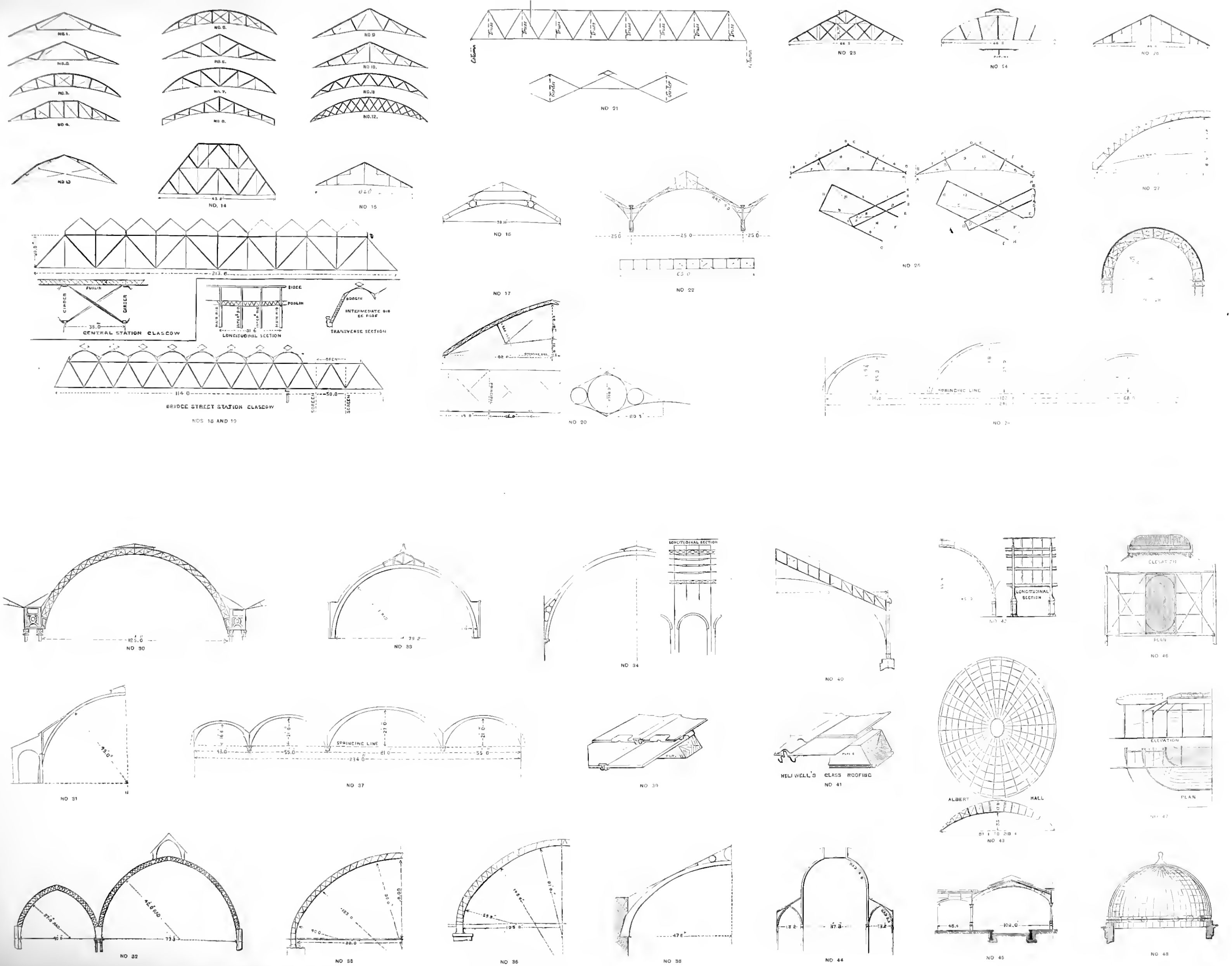
should be very happy to arrange the dimensions of the roofs in the form of a diagram. He was very glad that there had been some remarks made about the Bower-Barff process, but he should have been glad to have heard a little about the process of galvanising, because it was generally understood that this process rendered iron brittle. As to the roof of the Hide and Skin Market at Manchester, about which Mr. Schönheyder asked a question, one side rested on a building, and the other side rested on a pillar with a small side span. The question of large or small spans has been alluded to. In the St. Pancras roof there was a width of 240 feet in one span. At the Victoria Station of the London, Chatham, and Dover Railway Company, there was a width of a little over 240 feet in two spans. Paddington Station was 240 feet, in three spans; and York Station was 234 feet in four spans. These formed a series of roofs of practically the same width, and having one, two, three, and four spans, respectively. He thought that if a roof was built upon a curve in plan over a railway it was very important to have only one span, as at Bristol, for he had observed that at York Station, where there were four spans, the columns came in the way, and made it difficult for the guards to see from one end of the train to the other, or to observe the signals. The span of the Bristol roof was only 125 feet. The price appeared high, but this was due to the roof being built on a curve, for no two purlins were of the same length. With regard to the pitch of a roof, he thought that it could be appreciated better when it was spoken of as a gradient of "one in so many," than when it was expressed by the angle. The price which he had stated as that of the Queen Street Station, Glasgow, did not include the cost of the covering. With that exception, the price he had given was he believed correct. It was sometimes difficult to separate the cost of the covering from the price. In some of the roofs, the price quoted included the covering, and in some it included only the ironwork without the covering. In the paper he had not wished so much to enter into questions of price as to give different types of roofs, for the purpose of ascertaining what type ought to be adopted for any special case. The cost of roofs was very misleading, on account of the variations in the cost of iron and labour. He knew several firms who had taken roofs at a low price when they had not been busy, on purpose to keep their men employed. It would not be fair to compare the price of a roof made under such circumstances with the price at which a roof would be executed by a firm that was very busy. Mr. Schönheyder had made a remark about the eyes of rods in roofs. He (Mr. Walmisley) might remark that at the Earls Court Station, which was a metropolitan station,

instead of terminating one rod and uniting it by a short link to the next connection, they had made it all in one. They had really got a bar with two heads forged on it at the end, and the holes were drilled. This was the only example which he knew in which they had done away with the short link connection which was generally adopted in roof construction. He thought he had alluded to the principal points raised in discussion, and that nothing remained for him now, but to thank the meeting for the kind way in which the paper had been received.

The President said that he had not yet gathered which was the best size to adopt for the span of a roof. The large ones appeared to be expensive, and he really did not think that they were the most advantageous or the best in appearance. As to the cost of roofs, some engineers would have all their forgings complete and perfect in shape; they would have the holes drilled, and the pins turned, and everything properly tested. When that is the case the cost of a roof would go up two or three pounds a square directly. He must say that he thought that all the holes ought to be drilled, and all the pins turned. He thought that in one of the bridge accidents there arose the question whether the structure did not go down to a great extent through the holes not being perfect one with the other, and the tie-rods being allowed to play. Had the holes been drilled, and turned steel pins used, there would have been no play. He had not heard of many roofs failing through any weakness of construction. The paper contained so many examples of roofs, that when it appeared in the 'Transactions' engineers would be able to refer to it, and use it almost as they would use data and formulæ, and in years to come they would be obliged to the Author when they looked back at the 'Transactions.' He (the President) must say that he had never seen a better sample of diagrams. As to the Barff process, he had had samples sent to him, and he saw no sign of the coating giving way. If the coating would stand the atmosphere of London, it would stand anywhere. Cast-iron coated by Dr. Angus Smith's process would corrode, after having been exposed in London some time. The atmosphere of London was such that it would eat through anything. He expressed the thanks of the Society to the Author for his excellent paper.

EXAMPLES OF FIFTY IRON ROOFS.

Name of Roof.	Length.		Total Width.		No. of Spans.	Maximum Single Span.		Distance apart of Principals.		Total Rise.		Rise of Tie-rod.		Depth of Principal.	
	ft.	in.	ft.	in.		ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.
St. Pancras Station, M. R.	690	0	240	0	1	240	0	29	4	96	0	..		6	0
Glasgow, Central Station	560	0	213	6	1	213	6	35	0	..		..		20	0
Birmingham, New Street Station..	840	0	212	0	1	212	0	24	0	40	6	17	6	23	0
Liverpool, Lime Street Station (new roof)	645	0	403	0	2	212	0	32	0	44	9	22	0	22	9
Manchester, Central Station	550	0	210	0	1	210	0	35	0	84	10	..		5	3
Glasgow, St. Enoch Station, G. & S. W. R.	518	3	198	0	1	198	0	36	10	78	9	..		5	0
Cannon Street Station, S. E. R. ..	653	0	190	4½	1	190	4½	33	6	60	0	30	0	30	0
Glasgow, Queen Street Station ..	415	0	170	0	1	170	0	41	6	46	0	14	9	31	3
Charing Cross Station, S. E. R. ..	490	0	166	0	1	166	0	35	0	45	0	25	0	20	0
Liverpool, Central Station	495	0	..		..	160	0	55	0	40	0	14	0	26	0
Carlisle Citadel Station	1002	6	279	0	2	154	6	40	6	..		..		15	0
Liverpool, Lime Street Station (old roof)	..		153	6	1	153	6	21	6	36	0	24	0	12	0
Exeter, St. David's Station	360	0	132	0	1	132	0	15	0	22	0	5	0	17	0
Victoria Station, L. C. & D. R. ..	385	0	256	4	2	129	0	35	0	31	6	8	6	23	0
Agricultural Hall	400	0	220	0	3	125	0	24	0	51	0	..		3	4
Bristol Junction Station	500	0	125	0	1	125	0	18	9	31	3	10	5	20	10
Victoria Station, L. B. & S. C. R.	734	0	242	0	2	124	7	50	0	..		..		10	9
Paris Exhibition, 1878, Machinery Halls	2150	0	116	9	1	116	9	49	0	48	0	41	9	6	3
Glasgow, Bridge Street Station ..	600	0	163	0	2	114	0	31	6	..		..		12	0
Liverpool Street Station, G. E. R.	624	0	309	0	4	109	0	30	0	35	6	25	6	10	0
King's Cross Station, G. N. R. ..	792	0	210	6	2	105	3	20	0	50	6	..		2	0
Paddington Station, G. W. R. ..	700	0	240	6	3	102	6	10	0	33	9	..		1	8
Birkenhead, Woodside Station ..	375	0	118	11	2	97	11	25	0	25	0	14	8	10	4
Edinburgh Drill Hall	135	0	97	6	1	97	6	13	6	27	0	13	6	13	6
Earls Court Station	360	0	96	0	1	96	0	20	0	24	6	2	0	22	6
Broad Street Station, N. L. R. ..	460	9	190	0	2	95	0	36	10	17	0	4	6	12	6
Sunderland Station, N. E. R. ..	470	0	95	0	1	95	0	10	0	35	0	..		1	8
Birmingham, Snow Hill Station ..	506	0	150	3	2	92	0	22	0	27	6	18	6	9	0
Coventry Market	160	0	..		1	90	0	8	0	45	9	..		1	3
Manchester Skin Market	201	11	113	0	2	90	0	32	0	46	0	..		2	0
Leeds Station, N. E. R.	462	0	244	0	3	89	0	12	8½	28	6	9	0	19	6
London Bridge Station, L. B. & S. C. R.	660	0	266	0	3	88	0	16	0	27	0	9	0	18	0
Blackfriars Station, L. C. & D. R.	401	6	209	4	5	87	3	32	3	22	0	13	0	9	0
Paris Exhibition, 1878, Industrial Halls	..		82	0	1	82	0	16	4	17	0	1	8	15	4
York Station, N. E. R.	795	0	234	0	4	81	0	10	0	27	0	..		1	9
Westminster, Royal Aquarium ..	340	0	..		..	80	0	20	0	40	0	..		6	6
Alexandra Palace, Great Hall ..	..		79	2	1	79	2	25	0	39	7	..		1	10
Penzance Station, G. W. R.	250	0	77	0	1	77	0	15	7½	12	6	2	0	10	6
Middlesborough Station, N. E. R.	309	0	119	3	2	76	6	20	2	44	0	..		2	0
Derby Drill Hall	150	0	75	0	1	75	0	15	0	30	0	..		2	0
Oban Station	270	0	..		..	71	6	30	0	..		..		7	10
Port Elizabeth Drill Hall	..		70	0	1	70	0	..		15	1	5	9	9	4
India Office Court Yard	113	6	66	3	1	66	3	..		16	4	nil.		16	4
Tunbridge Wells Gasworks, Retort House	200	0	65	0	1	65	0	25	0	..		..		5	0
Swansea Station	..		70	0	2	64	6	20	0	16	0	1	0	15	0
Dublin Gasworks, Retort House ..	296	1	64	3	1	64	3	6	6	33	0	5	0	28	0
Perth Station	..		115	0	2	57	6	8	2½	11	6	2	3	9	3
Brazil, Nitheroy Gasworks	162	6	50	0	1	50	0	12	6	..		..		6	0
Millwall Docks, Grain Warehouses	211	0	924	0	21	44	0	15	0	8	9	nil.		8	9
Glasgow, Blythwoodholme Arcade	132	9	39	10	1	39	10	12	6	..		..		..	


NO 1.
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NOS 18 AND 19
CENTRAL STATION GLASGOW
LONGITUDINAL SECTION
TRANSVERSE SECTION
INTERMEDIATE RIB OF ROOF
BRIDGE STREET STATION GLASGOW
NO 20
NO 21
NO 22
NO 23
NO 24
NO 25
NO 26
NO 27
SPRINGING LINE
NO 30
NO 31
NO 32
NO 33
NO 34
NO 35
NO 36
NO 37
NO 38
NO 39
NO 40
NO 41
HELIWELL'S GLASS ROOFING
NO 42
ALBERT HALL
NO 43
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NO 46
ELEVATION
PLAN
NO 48

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December 5th, 1881.

CHARLES HORSLEY, PRESIDENT, IN THE CHAIR.

ON THE ARRANGEMENT, CONSTRUCTION, AND MACHINERY OF BREWERIES.

By W. BARNS-KINSEY.

It is proposed to treat this subject under the following heads.

1st. General principles which should govern the arrangement of the buildings and machinery of breweries.

2nd. Wells and water.

3rd. The machinery used in the operation of brewing, which may be divided into six sections—(1) Pumping, (2) Grinding, (3) Mashing, (4) Boiling, (5) Cooling, and (6) Fermenting and Cleansing.

Brewing is essentially a chemical operation, and its success is controlled by a variety of influences, atmospheric, chemical, and electrical, which therefore claim attention in the choice of a site, and arrangement of buildings and plant. The first necessity is an inquiry into the quantity and quality of water, as without a plentiful supply of suitable water a site otherwise eligible may be useless for a brewery, and therefore every means should be taken to ascertain this. In some cases it may be necessary to make costly borings, which may after all fail to find water, or when found only prove that it is of an unsuitable character; still the money expended can never be wasted, as loss and disappointment will thereby be prevented. In some towns the public supply may be more suitable for brewing than the water from a well sunk on the premises, in which case the latter may be used for cooling and washing purposes only. The storage of rain-water may also form an important part of the economy of the brewery.

The site should be as open and airy as possible, out of the influence of gasworks or noxious trades, and so situated that it may be readily drained.

The drainage of a brewery, next to the water supply, is of the utmost importance, as the refuse of breweries rapidly ferments, and becomes more foul than ordinary sewage; all drains should

therefore be arranged with a quick fall, efficient traps being placed between the tributary and main drains, the latter again being cut off from direct communication with the town sewer; and all drains should be ventilated at their highest points, and be provided with proper air inlets. By this means a constant current of fresh air will be kept circulating throughout the whole system of drainage, and with this fall and suitable automatic flushing the formation of sewer air and deleterious gases will be prevented.

A level plot of ground is unnecessary, in fact it may be a disadvantage, as rising ground may be so utilised that the various parts of the building containing the vessels which command one another may be constructed without necessitating any portion being of great height. An important consideration is, conveying the raw material to, and delivering the beer from, the brewery; a railway siding, canal, or river, is therefore of great advantage when the brewery can be placed alongside.

Natural ground should always be chosen, that is ground which has been undisturbed, both on account of the greater security obtained for the foundations, and also for freedom from exhalations to which made ground is liable.

Both buildings and plant should be so designed that extensions may be made without disturbing the general arrangements, and as a rule it is advisable that the various utensils be placed to command each other, so as to avoid pumping; thus the cold water (or liquor tank as it is called) should be at the top of the building, and command the hot-liquor back, which in its turn should command the mash tun, the mash tun the under back and copper, the copper the hop back, the hop back the coolers; and refrigerator, and thence to the fermenting tuns, &c. This of course is easily arranged in breweries on a small scale, but in large ones the height of the buildings would be objectionable, and it is therefore usual to pump the wort at some intermediate stage, and allow it to gravitate afterwards; the point at which the wort may be pumped with the least risk of acidity in the after processes has been much discussed, but most brewers consider it best to pump the boiled wort from the hop back to the coolers, which may be placed on the top of the building, and from these the wort would gravitate to the fermenting tuns, &c. It is of great advantage in keeping the brewery free from steam that the coolers, coppers, and hop back, should be in a distinct building.

The tun room should have its windows facing the north, and, when the size will admit of it, the walls should be built hollow; the roofs both of tun room and cooler floor should be tiled, in

the latter case the tiles may be laid on battens, as the vapour is absorbed by the tiles, which also resist heat better, and the reek does not condense and return to the cooler; but in the case of the tun-room roof the battens should be laid on boarding and felt, and a ceiling formed on the rafters and ties beneath with Hitchen's slab plaster, which is preferable to lath and plaster as being lighter and more endurable, an air space will then be formed between the ceiling and the roof, which will assist in keeping the tun room at a low temperature during the summer. The hop and malt stores should be similarly ceiled, and be kept as close as possible, but in all other parts of the brewery ample ventilation should be provided.

For brewery work, whether for walls or floors, concrete is an excellent material. Locality must of necessity govern the materials of construction, but the hardest available material should always be selected for working floors. Crushed brick or clinkers, mixed with Portland cement in the proportion of 3 to 1, so as to make a fine concrete of about 1½ inch in thickness, and then run on to a bottom concrete bed of 6 inches thick, the ballast of which has been broken to pass through a 1½-inch ring, makes an excellent floor. The latter concrete may be made with selenitic cement in the proportion of 6 to 1, with one-seventh of Portland cement added to the selenitic to hasten setting, and the top finish of fine concrete should be applied in the form of thick grout, and at once floated to a fine face; this will prevent the flaking off of the surface which always takes place when the cement face is, so to speak, plastered on to the concrete bed after the latter has set. Concrete paving for breweries should be finished off in a continuous operation.

Asphalte on concrete is also a good paving, but is open to the objection of being indented when barrels stand upon it for a considerable time, as in stores; and with both stone and brick paving there is considerable difficulty, as the yeasty matter penetrates the joints and destroys them.

Excellent cellarage may be formed with concrete by digging out the earth in trenches to form the side walls, the curve of the arching being formed upon the surface of the ground. The concrete is then filled in, and the surface above the cellar finished, the earth beneath being afterwards excavated. The specimen of selenitic concrete produced is composed of six parts broken brick and clinker to one part selenitic cement with one-sixth Portland, and was taken from the arch of a cellar constructed in this manner under my directions. The span of the arch is 10 feet 6 inches, thickness of crown 6 inches, the rise 1 foot 6 inches. The brewery was built above, and the engines

and machinery placed upon the arch, the earth beneath being removed when extension of the cellarage was required three years afterwards.

Cellars may also be constructed by building up the side walls with $4\frac{1}{2}$-inch brickwork in cement, with occasional headers, and filling up between the brickwork and earth with concrete; the arching being formed by curved corrugated iron, springing from rolled-iron girders, and filled in on top with concrete. Some large store-cellars were in this manner constructed from my plans, the beer being stored away beneath before the concrete arching above was completed; this would have been impossible with the usual centering and brick arches.

For dray-horse stables, and cart and cask sheds, the author found concrete both cheap and durable.

Wells and Water.—Good water in a brewery is of the utmost importance; but what should constitute the composition of a good brewing water is with brewers a much debated question. Perhaps nothing in nature is more variable than this apparently simple fluid, which, however, is not always what it seems, being often a mixture of alkaline and metallic salts, acids, gases, and, unfortunately, sometimes animal and vegetable matter, some of which are held in chemical union, and others in mechanical suspension. Pure water, or hydrogen-oxide, is only obtained in the laboratory.

Some brewers prefer soft and others hard water, whilst a few are indifferent on this point. Were the density of the worts and the value of cold water for refrigerating and other purposes alone to be considered there would be little hesitation in their choice; but the constituents of the water *are* of importance, accordingly as the beer to be brewed is to be drunk speedily, or is intended to be kept for a prolonged period; therefore, though a brewer already established can seldom choose a different spring or stream, the case is much altered when the site of a new brewhouse is to be selected, and a knowledge of the quality of water suitable for the various classes of beer is therefore necessary to the engineer to enable him to rightly advise his client. Water entirely free from saline matter, or which holds it only in very small quantity is unfit for brewing.

In England nearly every one at all acquainted with brewing holds that water which contains a large quantity of gypsum (sulphate of lime), earthy carbonates, and no organic matter is best adapted for this purpose.

Hassall gives an ingenious reason for this, although he believed it is entirely speculative, and not based on experiments. He says: "During ebullition, the excess of carbonic acid in the water, by

which the carbonates of lime and magnesia are retained in solution, is expelled, and those salts are precipitated. Again, the alkaline phosphates present in malt have the power of converting sulphate of lime into phosphate, which is thrown down; an alkaline sulphate which is soluble being formed. The greater part of the phosphate of lime produced is redissolved in the acid generated during the fermentation; consequently the water, from being hard, thus becomes comparatively soft, and in this state is well suited for extracting the active properties of malt and hops."

Another advantage claimed for the use of hard water is, that more saccharine matter can be left in the beer, by which its fulness and flavour will be increased and liability to after acidity prevented.

German brewers consider the presence of mineral salts in water as bad, upon the principle that the action of these salts in producing hard water in the mashing process is very much the same as that which occurs when peas or beans are boiled in hard, as compared with the result when boiled in soft, water; soft water extracting the albuminous matter more readily; the German brewer wanting to get all that is possible out of the malt.

English brewers, on the other hand, working on a different system, and brewing beers which are not intended to be drunk for some months afterwards (as in the case of stock, or season brewed beers), are justly afraid of having too large a quantity of albuminous matter in the solution from the mash, because these albuminous constituents are the most powerful agents in continuing fermentation beyond the point at which they wish it to cease.

Water loaded with organic matter, like that of the Thames, is a decided loss to the brewer, as the vegetable and animal remains are decomposed during brewing, and carry with them some portion of the strength of the wort, besides rendering the beer liable to spoil.

The success of the Burton brewers arises in a great measure from the quality of the water they use. This is not taken, as many suppose, from the river Trent, but from wells sunk in the underlying conglomerates and gravels; the Trent valley in the immediate neighbourhood of Burton consisting of a deep excavation in rocks composed principally of sandstones and marls, the latter containing numerous irregular-bedded masses and veins of gypsum, and, rarely, thin bands of arenaceous limestone, which may be briefly described as belonging to different sub-divisions of the new red sandstone.

The analysis of water used at Messrs. Alsopp and Sons' brewery gives in grains per imperial gallon:—

Chloride of sodium	10·12 grains.
Sulphate of potash	7·65 „
Sulphate of lime	18·96 „
Sulphate of magnesia	9·95 „
Carbonate of lime	15·51 „
Carbonate of magnesia	1·70 „
Carbonate of iron	0·60 „
Silica	0·79 „
Total	65·28 grains.

Analysis of the water at Messrs. Bass and Co.'s brewery gives:—

Carbonate of lime	9·93 grains.
Sulphate of lime	54·40 „
Chloride of calcium	13 28 „
Sulphate of magnesia	0·83 „
Total	78·44 grains per gallon.

On boiling, these waters deposit a large amount of carbonates of calcium and magnesium, besides a small quantity of calcium sulphate; a little iron which it contains becomes also eliminated. A varying amount of carbonic acid in the uncombined state keeps the carbonates in solution. Dr. Graham has stated that though sulphate of lime has certainly very much to do with the properties of the Burton water, nevertheless something is due to the chlorides of sodium, magnesium, calcium, &c., likewise present. Practical brewers are aware that in many cases when the water contains a certain quantity of chlorides, the ale produced is as much to be depended on for its long keeping qualities as that made with water containing sulphate of lime.

In certain districts where brewers are compelled to use soft water, or that which runs off moors or fens, for want of better, they should impregnate them at second hand with gypsum, or with such limestones as are easily procurable. This plan I have found most serviceable, enabling ale to be brewed having the characteristics of that of Burton. The addition of a certain proportion of salt as well as gypsum to soft water, renders its imitation of Burton water still more complete.

In fixing the positon of the well, the surroundings should be taken into consideration, and every care taken to prevent the

percolation of drainage or surface water, which as a rule contains organic matter. This may, in the course of running sand or strong springs, be accomplished by means of cast or wrought-iron cylinders carried down to a certain depth, and of sufficient diameter to take the pumps, or the well may be steined with concrete, the earth being excavated as far as found safe, a drum placed within the excavation, and the space between it and the earth filled in with concrete, the drum being raised as the work proceeds; this makes both a cleaner and better job than brickwork. The lower portion of the well would of course be constructed in like manner, but of smaller diameter than the upper.

A boring of 6 inches or 9 inches diameter may be constructed from the bottom of the well when the sinking can no longer be proceeded with. Concrete tubes of 4 feet diameter make good steining in place of the before-mentioned concrete or iron cylinders, their weight assisting them to travel as the excavation is made, this is an advantage, especially in clay soils.

In localities where the surface, and even the upper water of the lower springs is contaminated, he preferred to bore from the surface, and line the boring with cast-iron pipes, driving these down as far as possible, and then telescoping, so to speak, with pipes of smaller diameter, until the required depth is reached. The advantage of this method of sinking is that the quality of the water may be tested at various depths, as it is sometimes of advantage to have two qualities of water. For instance, good water for brewing pale ale is not so suitable for stout.

When the required depth of boring is reached, the space between the inner and outer tubes is filled in with Portland cement, run in in the form of grout, a quick-setting cement being required for this purpose.

The well, if sunk, is better placed outside the brewery; but in the case of artesian borings, the author has found it to be an advantage to have it in or near the engine-room, the pump being placed within the bore-tube, and connected direct to the engine, traps in the various floors of the brewery facilitating the withdrawal of pipes or pump-rods.

The next point for consideration is the machinery used in the operation of brewing, under the heads of pumping, grinding, mashing, boiling, cooling, fermenting, and cleansing.

Pumping.—The water, or "liquor," has nearly always to be pumped, and in some cases the wort and beer also. As the pumping of wort or beer will be more particularly referred to hereafter, the author will only at present deal with pumping the water, or, as it is termed in the brewery, "liquor."

A good supply of this most important liquor is always necessary, and is generally best obtained from a well. A high service of water is in some towns supplied by waterworks, and occasionally used for brewing; this, of course, saves pumping, but well water is generally colder, and therefore better suited for refrigerating and attemperating.

The pumps should be large enough to do their work in a short time, so that in breweries of large size the machinery need not be worked for pumping only. The liquor is stored in a vessel called a "cold-liquor back," the capacity of which should be about six barrels per quarter of malt brewed, but the contents may vary considerably. For instance, if there be a regular and good supply of liquor, the back need not be so large as when the supply is irregular. It should not be unnecessarily large, as it must be borne in mind that fresh liquor is best for brewing. It is sometimes made of wood if indoors, but always of iron if out of doors. Cast iron is the best material for the latter. Wrought iron is occasionally used for indoor backs. The iron is sometimes galvanised, but is not preferred. A few cast-iron backs have been enamelled inside, but it doubles the cost, and is an unnecessary refinement.

The "cold-liquor back" should be the highest utensil in the brewery, and command all the others. It is not uncommon to make it serve as a roof to a part of the building; but the author considered it objectionable, particularly in towns, to have the liquor exposed to the atmosphere, and it is best roofed over. Whether outside or inside easy access must be arranged for cleaning, &c. It must on no account be placed over utensils from which steam will arise, as the steam readily condenses upon the cold iron, and becomes a nuisance.

In proportion, the width is frequently about half the length; it should not be very deep, say three or four feet, because, as it is the highest utensil, it requires a number of supports, and if shallow the weight is spread over a larger area. The back, when full, weighs about 4 cwt. per barrel if made of wood or wrought iron, and about 5 cwt. per barrel if in cast iron. If constructed of cast iron it should be made in flanged plates of convenient size, bolted together with wrought iron bolts. When made of wood the best Dantzic fir should be used. In places where there is a deficiency in the supply of liquor cold enough for refrigerating or attemperating, machines for artificial cooling are frequently used. Sometimes the machines are used for making ice, which is afterwards put into the liquor, but more frequently the liquor is made to circulate through the machine,

the temperature being thereby reduced to about 40° Fahr., thus economising the quantity of liquor required.

Grinding.—It is essential to have the natural cohesiveness of the grain destroyed in such a way that the water may have free access to every particle of it, in order to ensure the entire extraction of the valuable constituents. Various methods have been resorted to to effect this by reducing the grain between stones in the ordinary way, or in steel mills, as when coffee is ground, or by crushing between rollers, the latter being preferable, as the object is to disintegrate the grain completely, and loosen the husk from the fleshy parts without separating the two. A moment's consideration will show that the smooth rollers, as ordinarily used, fulfil these conditions better than the first two methods, and a considerable advantage is thereby gained when the mash is racked off; for when the malt is ground fine it is apt to "set" and form a mucilaginous mass, which retains much of the liquor, which cannot be removed except by long washing, rendering the worts dilute, and exposing them to the danger of acetification in the after-treatment. When the particles of the grains still adhere, though their texture is broken, each shell forms, as it were, a filter, through which the clear liquor readily percolates; but if the grain be torn or sliced, as with steel mils, the contents of the grain remain to some extent adhering to the husk, and loss will ensue, because the water will not penetrate it during the time allowed for mashing.

That this is the case is evident from the well-known fact that dried malt will float on water for twenty-four hours, without absorbing enough of the liquor to increase its gravity sufficiently to cause it to sink.

The rolls should be capable of crushing as many quarters per hour as are mashed in one operation; their dimensions vary from 8 inches diameter and 8 inches wide to any required size.

It is now generally preferred to make one roll about twice the diameter of the other, and to drive the larger roll, the small roll revolving through the friction of the malt passing between them. The roller frames are furnished with set screws, in order that the space between the rolls may be adjusted.

It is essential that wire screws be provided to take out the dust, stones, &c.; some mills are furnished with a second set of rolls of smaller diameter, for crushing the smaller grain which has passed through the screens. The rolls being set for large grain would not crush the smaller. The malt mill should not be driven too fast, or the grist becomes heated; a speed of 180 to 200 feet per minute periphery is found a good average.

The position of the malt mill in a brewery is important, as the malt hopper, generally made of wood, should be commanded by the malt store, so that the malt can be readily shot into it, and run direct to the rolls; an elevator, consisting of tin cups on an endless leather band, being used to lift it vertically, while an iron screw revolving in a tube, termed a "creeper," is used to convey the grist (when required) from the elevator in a horizontal direction. Whether delivered from the elevator or creeper, the grist usually runs into a hopper, called a "grist case," erected over the mash tun; this is generally made of wood, the large ones sometimes of iron. It, like the malt hopper, should contain sufficient for one brewing.

When the malt store is in the upper part of the building, it must be furnished with sack tackle for raising the sacks of malt, the same tackle being used to raise the hops to the hop store, which often adjoins the malt store.

It has been found in practice that it is not advisable to construct malt mills for crushing more than 30 quarters per hour, and in large breweries it is therefore usual to have two or more mills, one being kept especially for crushing the black and brown malt of which porter is made.

Mashing.—Mashing is the most important part of brewing, as by it the brewer extracts the saccharine principle from the malt, and hence his profit depends on the success of the operation. The process of mashing depends on the action of diastase upon starch, under the influence of heat and moisture. Roughly speaking, diastase has the power of converting 2000 times its own weight of starch into grape sugar.

Diastase is, by long digestion, dissolved out in greater quantity from the malt at low temperature than at high, and it has been observed that the temperature at which its solution is most complete is between 100° to 140° Fahr., whereas the temperature at which it is most active in converting the soluble matters of the mash into a sugary or saccharine form is much higher. At low temperatures dextrine is uniformly produced with the sugar, and then as the temperature gradually rises more and more of the sugar is obtained, until a point is arrived at at which this action upon dextrine can go no further.

The process of mashing differs somewhat according to the use to which the worts are to be put. It is the object of the brewer to have a dense extract which shall neither acetify nor be wholly converted into alcohol, reserving the greater portion of the malt extract for communicating to the beer richness and flavour. The first important point is complete abstraction of the soluble substances of the malt, and the next, to accomplish

this with the smallest possible quantity of liquor, being rigorously careful to prevent acetification; six or seven barrels of water per quarter of malt are generally sufficient for the exhaustion, of which $2\frac{1}{4}$ to $3\frac{1}{4}$ barrels are lost in the after operations of boiling and fermenting.

The operation of mashing is performed in a vessel called a mash tun, by means of manual labour or machinery. The mash tun itself should contain from 3 to $3\frac{1}{2}$ barrels per quarter of malt to be mashed, it must be of cylindrical form, and from 3 to 6 feet deep according to the capacity required. It is constructed of English oak staves, with Dantzic fir bottom, or of cast iron put together as described for the cold-liquor back. In position, the mash tun must be commanded by the hot-liquor copper, or other utensil in which the liquor is heated, and in its turn must command the vessel in which the wort is boiled, unless, as in some cases, the wort is pumped up into the copper to be boiled.

Many years ago, mashing was performed by simply stirring the grist with the heated liquor by means of wooden oars, which, however, often left considerable portions of the wetted grist, termed "goods," untouched, and consequently unproductive. A mashing machine was then introduced, and it is believed patented in 1807, which has been used, with few alterations, to the present day. It consists of a vertical shaft, driven by steam power from above, and working in a foot-step with gun-metal bearing, bolted to the centre of the bottom of mash tun inside; half way down the mash tun, inside, is bolted a toothed rack, in which works a toothed pinion on end of an iron shaft, and the other end of the shaft works in a gun-metal bearing, attached at its proper height to the vertical shaft. This horizontal shaft, or "rake shaft" as it is commonly termed, works round the mash tun by the vertical shaft revolving, and in its turn is made to revolve by a pair of level toothed wheels, one on the vertical shaft, and one on the rake shaft. The rake shaft is provided with a number of wrought-iron rakes, generally about 8 inches wide, and by these means the mashing is effectually accomplished. There are other forms of mashing machines to work without power; they may be generally described as vertical copper cylinders, having a jacket or water space all round. Between the inner and outer cylinder the water circulates, and rushes horizontally into the inner cylinder through a number of small holes; the grist, falling through the inner cylinder from the hopper above in a vertical column, is wetted by the horizontal streams of liquor, and so falls into the tun mashed. The object is to thoroughly wet every particle of grist in the shortest

possible time, so that there may be no loss of heat; and the various forms of machines, of which those named may be taken as typical, have this object in view.

The mash tun is provided with a false bottom, to strain the wort from the grains. The extract is called wort when it is drawn from the mash tun, and that left behind is called grains. The false bottom is usually made of cast iron, in plates of convenient size to handle, the thickness being about three-eighths, and having perforations about 1 inch apart all over, by $\frac{1}{16}$ inch diameter, and countersunk on the under side; these holes are drilled, to ensure regularity of size. Very excellent false bottoms are made with long slots radiating from the centre towards the circumference of the tun, these drain more rapidly than the perforations. Gun-metal and copper plates are now often used in place of iron, and are both lighter and more durable.

The bottom of the mash tun is sometimes fitted with a gun-metal door, through which the grains are thrown when done with, instead of over the side of the tun.

The wort is drawn from the bottom of the mash tun by means of several cocks or taps, called "spend taps"; from four to six is the usual number, as it is the object of the brewer to draw from all parts of the tun, and to get his wort perfectly bright, and having several taps enables him to close one or more should the wort from them be running thick. After the first mash is completed, a further quantity of hot liquor is put over the goods by means of the "sparger." This sparger has a copper basin in the centre, with two or more perforated arms extending to the side of the mash tun; it revolves upon a centre by the action of the liquor passing through the arms, on the well-known principle of Barker's mill. When an internal mashing machine it used, the basin runs on wheels fixed to a carriage on the upright shaft. When the wort is drawn from the mash tun it runs into a vessel called the under back, which need not be of sufficient size to hold the whole quantity of wort, as it should be at once run or pumped up into the wort copper.

The mash tun is sometimes provided with a steam coil beneath the false bottom, for keeping up the bottom temperature, as also with a pipe for letting in hot liquor for a similar purpose. A steam coil should be also provided to the under back.

Boiling.—Boiling the worts is practised with the object of removing the excess of nitrogenous matter; for if this were permitted to remain it would undergo putrid fermentation, and

destroy the whole product. It also diminishes the liability to acidity by expelling the contained air. Boiling is also requisite for the expulsion of the excess of liquor used in the mashing, as well as for the transformation of any starch which might still remain into glucose and dextrine. There is a further important object in boiling, namely, the extraction of the valuable bitter and aromatic principles of the hops, whereby the flavour of the wort is improved and an agreeable aroma imparted to it.

Boiling Coppers.—The " liquor " for mashing has to be heated, and the wort has to be boiled; the former should perhaps have been described before mashing, although from both operations being often done in the same manner, he proposed to treat them under the same heading.

The liquor for mashing is generally heated by means of a steam coil in a circular or rectangular vessel, called the "hot-liquor back," which may be constructed of wood, iron, or copper; its capacity should be from 3 to 4 barrels per quarter. The outlet end of the coil may be so regulated that only condensed water shall flow from it, and this may be utilised by running it into a tank for cask washing, &c. At Burton, the practice is to heat up the liquor, and then cool it down to the required temperature for mashing by means of a coil through which cold water passes. Steam blown direct into the liquor has sometimes been used, but it often affects the quality of the liquor, and is in other ways objectionable. The wort is boiled by several different means, and it is an open and much debated question whether direct fire, heat, or steam is the best. Brewers differ much on this point, but steam is daily increasing in favour. The author's own opinion is that when the brewing liquor is soft, direct fire heat is the best, because, from soft water being more extractive, there is a larger amount of nitrogenous matter in the wort, which is more readily converted or cooked by the higher temperature of the fire copper; still the steam copper has much to recommend it, on account of its ease of manipulation, cleanliness, and convenience of erection. Whether the wort is boiled by fire or steam, the coppers are now generally open.

In boiling worts by steam, a wooden tub and coil, or a copper vessel and coil similar to those described for hot liquor, may be used; but there is an objection to both, owing to the difficulty of removing the spent hops from between the tubes of the steam coil. This, to some extent, has been obviated by putting in a false bottom of iron, gun metal, or copper, similar

to that described for the mash tun, so as to keep the hops from the steam coil; but the boiling is then not so satisfactory as with the fire copper.

The hops are run out through the discharge pipe with the wort, and then thrown up again from the hop back for the second wort. If the wooden tub or copper vessel be provided with a false bottom, the hops remain in ready for the second boiling.

Undoubtedly the best method of boiling by steam is by means of the jacketed copper, which consists of a hemispherical pan of copper, made entirely in one piece, with a cast or wrought iron jacket outside it, a space of from 2 to 3 inches being left between the jacket and the pan, the steam space being made tight at the junction of the copper and iron pans.

Above the pans the copper is continued to the required height for capacity, this portion of the copper being comparatively thin, having to bear no pressure, while the copper pan and iron jacket must be of sufficient substance to withstand a steam pressure of about 30 lb. on the square inch.

The jacket into which the steam is admitted is provided with a cock in its upper part for the escape of the heated air, as also a safety valve to prevent undue pressure; unless these are provided and attended to an explosion is exceedingly likely to take place, owing to the great expansive force exerted by air suddenly heated. The wort is discharged through the centre of the bottom, the pipe passing through the steam space between the copper and the jacket. A condensed-water pipe must be provided from the jacket which may either be regulated by a cock or a steam trap, so that condensed water may alone pass to the condensed-water tank. The latter tank should receive all condensed water from the various steam coils for use in the steam boilers or cask yard.

The capacity of the wort copper should be about three barrels per quarter, which leaves sufficient space for boiling.

Its position where the wort is not pumped should be such that it is commanded by the under back into which the wort runs; but when the wort is pumped it is generally placed sufficiently high in the brewery to command the hop back, coolers, &c.

Large wort coppers are often fitted with a "rouser," for the purpose of keeping the hops from settling on the bottom of the copper and burning. It consists of a vertical shaft, having horizontal arms from which chains are suspended in festoons; the shaft is kept slowly revolving by steam power, and the chains drag on the bottom.

When the boiling is completed the discharge cock of the copper is opened, and the whole contents run into the hop back. The hop back is generally of a rectangular form, from 3 to 5 feet deep, made of wood, iron, or copper, and fitted with a false bottom similar to that of the mash tun.

When the wort has remained in the hop back a sufficient time to settle, it is drawn off into the cooler, leaving the hops behind; and the hops, when thoroughly strained, are returned to the copper ready for the second boiling. This, in small breweries, is done by hand, but in large establishments an elevator is used very similar to that used for elevating grist or malt. In many cases the spent hops are afterwards pressed, either by screw or hydraulic presses, to extract the beer that has not strained from them in the hop back.

Cooling.—After the worts are thoroughly hopped and boiled it is necessary to bring them to a proper temperature for the commencement of the fermentation, which must be kept within certain limits. The worts require to be rapidly cooled; for if allowed to remain long exposed to the air, unless the atmosphere is very cold, acidity speedily ensues. The apparatus used in the first instance is known as the "cooler," and in the second the "refrigerator." In small breweries the wort copper is placed sufficiently high for the wort to run from it to the hop back and coolers; but in large breweries the copper is better placed on the ground floor and near to the boilers, so that one stoke hole may serve for both; the wort is, in this case, pumped up into coolers at the top of the building from the hop back. The coolers should always be placed in an airy situation, with moveable louvre boards on all sides if possible. Coolers are rectangular shallow vessels, generally constructed of Dantzic deal boards $2\frac{1}{2}$ inches thick at the sides and $1\frac{1}{2}$ inch at the bottom; the boards are connected by joists, to which they are secured by wood pins. The boards are also sometimes connected together by iron bolts running from side to side in the thickness of the boards; this enables the joints to be drawn together, and is on the whole preferable for small coolers and hop backs. The depth of the cooler is 6 inches; it should be perfectly smooth and free from large or dead knots, so that no impurities may be retained to be absorbed by the wood; it should have a gentle fall towards the fermenting tuns. and be placed in such a position that the air may have free access to it. There must be a limit, however, to this exposure, as even when the atmosphere is cooled and the coolers are of sufficient area to take the whole gyle, 2 inches or $2\frac{1}{2}$ inches deep, it requires six to eight hours to cool it to the required temperature, and even this

time is too long for the worts to be exposed to the air; hence the need of the refrigerator.

Considerable loss is often incurred by the imperfection of this method of cooling, especially in warm weather, for in the first place the wort is not reduced in heat so readily as to exempt it from acidity, while in the second the pores of the wood undergo considerable change in the alternate application of heat and cold, by which its pores are distended; therefore, if allowed to remain for any length, air enters, and this, coming in contact with the gyle in the next brewing, operates on the saccharine and albuminous constituents of the worts, and causes an incipient fermentation, technically known as the "fox." To obviate this, the cooler should be kept covered with water when not in use, and scrupulous cleanliness observed; a thorough washing with lime water also acts as a preventative.

On account of these difficulties attention has been directed to the use of other materials, both cast iron, wrought iron, concrete tiles, and copper, having been used, the most successful substitute being copper. A few years ago, Messrs. Truman, Hanbury and Co. erected some coolers made of sheet copper, which have proved most satisfactory, and no doubt the expense alone prevents the general adoption of copper coolers.

When coolers were depended upon almost entirely for bringing the wort down to the required temperature, usually 60° Fahr., they required to be very large, 100 square feet per quarter being needed, but refrigerators are now constructed of such power, and in fact are always used, that the coolers may now be much smaller and even two feet deep. In some breweries the cooler is dispensed with altogether and the work cooled direct from the hop back. He did not consider this a good plan, as a cooler or receiving back between the hop back and refrigerator allows much of the sediment to deposit which would otherwise be carried forward to the fermenting tun, and prove detrimental to the fermentation. Time would not permit him to do more than notice the various methods of refrigerating that have been brought out from time to time. Fans worked by steam power have been used to create a current over the surface of the wort in the cooler, and it has been much debated whether the wort should be exposed to the air by falling in a thin sheet, or lie in a shallow back with the cold water circulating through it by means of thin copper pipes. Of the former or vertical type are the refrigerators of Lawrence, Baudelot, Pontifex, and others; these occupy little floor space, but require from 3 to 6 feet of height. Of the latter or horizontal type may be mentioned Pontifex's oscillating refrigerators, Bridle's, Morton's, Riley's,

and others. In the vertical type of refrigerator the wort falls over a series of tubes, or over corrugations or plain surfaces of copper, the cold water circulating within the tubes, or between the vertical copper sheets, the wort falling in a thin stream or sheet externally.

In the case of Bridle's or Morton's, the refrigerator consists of a copper case, open on the top, in which is fixed a series of thin flat copper pipes, about $5\frac{1}{2}$ inches in depth and $\frac{1}{2}$ inch thick, at intervals of about $\frac{3}{4}$ inch; each pipe is divided longitudinally into two $2\frac{3}{4}$ inch pipes, through which the cold liquor passes in two columns, one over the other in opposite directions. The pipes are connected outside the case by metal boxes. The wort enters the case at the end opposite to that at which the cold liquor enters, passes underneath one pipe, rises to its level and then falls over the next pipe, and so on alternately over and under until it comes to the end, when it flows out to the fermenting tuns. This class of refrigerator takes up little height but greater area. Many other forms of refrigerators are made, but they, as a rule, fall under one or other of these types, and it is unnecessary to describe them.

Whatever refrigerator is used, it is the aim of the brewer to cool the wort as rapidly as possible, particularly when the temperature reaches 130°, as at this heat there is a greater tendency to acidify. The usual temperature to which the wort is cooled in this country, previous to fermentation, is from 58° to 60° Fahr.

Fermentation.—In the whole course of brewing there is no part of the process which requires such diligence and care as the fermentation of wort, for on it depends the success of the business. If the previous stages have been somewhat imperfectly accomplished, provided the products have not acidified, and a good fermentation is accomplished, a wholesome beverage is obtained; but let the mashing and other operations be ever so carefully executed, if the fermentation is bad an almost worthless product results. By care and moderate experience, however, brewing may be easily managed and uniform results obtained. He did not purpose to take up time by endeavouring to describe the theory, or chemistry of fermentation; but, to understand what is required of the engineer in designing the necessary apparatus, a few words of explanation are necessary.

In chemistry, by the term alcoholic fermentation is understood that change which sugar undergoes under the influence of the yeast plant; and which produces wine and all other alcoholic drinks. It serves as a type of a number of other

analogous phenomena known by the generic term fermentation, but specially designated by the name of the essential product of the particular phenomenon, as the alcoholic, the lactic, the acetic fermentation, &c.

The atmosphere is full of the germs of ferments, differing from the alcoholic leaven, and sometimes seriously interfering with the latter. They are the weeds of the microscopic garden, often overshadowing and choking the flowers. These are the lactic and putrid ferments, as the yeast plant is the alcoholic ferment of sugar. These organisms, which receive the common name of bacteria, are the agents of all putrefaction. Heat kills bacteria; cold numbs them; their active life is suspended by cold, and with it their power of producing or continuing putrefaction. Beer is assailable by all the organisms here referred to, some of which produce acetic, some lactic, some butyric acid; while yeast is open to attack from the bacteria of putrefaction.

For beer, moreover, the question of temperature is of supreme importance. "Bavarian beer" is prepared by what is called *low fermentation,* the name being given partly because the yeast of the beer, instead of rising to the top and issuing through the bung hole, falls to the bottom of the cask; but partly also because it is produced at a low temperature. The other and older process, which is called high fermentation, and which is that used in this country, is far more handy, expeditious, and cheap. In high fermentations, eight days suffice for the production of the beer; in low fermentation, ten, fifteen, or twenty days are necessary.

Great care is required in selecting the yeast, and keeping it fresh and free from influences calculated to impair its vitality, or by which it may contract any acidity or putrefaction which would prove detrimental to the beer by setting up lactic or acetic fermentation.

When the wort is run into the fermenting tun, yeast is added to induce fermentation.

The fermenting tun must be of sufficient size to contain the whole of one brewing or "gyle," with additional depth to allow room for the yeast formed in fermentation. The proportions of the fermenting tun are not very important, but most brewers prefer it to be a cube. It may be either round or square, and made of oak, Dantzic fir, or slate; glass has also been used, but there is a difficulty in keeping the joints tight. In Yorkshire the fermenting tuns, or stone squares as they are called, are constructed of slabs of stone, having an outer jacket through which water circulates.

It is very important to keep an even temperature during fermentation; every fermenting vessel, therefore, must be fitted with an attemperator, consisting of coils of tinned copper pipe, usually supported by brackets from the sides of the tun; although sometimes made portable, and suspended by chains or cords from above, so that they may be raised or lowered at pleasure. It is of great importance that galvanised iron stays or brackets should *not* be used to connect or fix the copper pipes, on account of galvanic action. The question of mixture of metals in a brewery producing galvanic action and consequent injury to fermentation, has been much debated, but the author was able to give them a very decided case from his own observation. He was consulted by a client with a view to discover a supposed defect in some of the utensils which prevented a sound fermentation; after a diligent search, commencing at the cold liquor tank and working downwards through the plant, he found the fermenting tuns, which had previously been without attemperators, fitted with portable ones, which had been purchased second hand. On examination, these proved to be constructed of copper pipe with galvanised iron stays. He assumed at once that fermentation was being retarded through galvanic action, and, in proof, removed the straps, substituting wooden ones, when no further trouble was experienced in subsequent brewings. For the same reason, galvanised iron should not be used for vessels containing wort, and tinned copper and gun metal should be used for pipes and fittings through which wort has to pass.

The attemperator is supplied with cold liquor, and when the temperature of the beer is rising, which it does during the process of "attenuation," or conversion of sugar into alcohol, a small stream of water is allowed to flow through the pipes; the main object of the attemperator being to check an increase of temperature, as, if the beer is permitted to get too hot, the mischief is done, and is not rectified by its being cooled down afterwards.

According to the old method of brewing, the beer was kept in the fermenting tuns for about three days, and the fermenting was afterwards completed in cleansing casks; but of late years "skimming" has come much into use, by which method the fermentation is completed, or very nearly so, in the fermenting tun.

Skimming consists in removing from the surface the yeast that has formed; this may be done by hand, but it is an unsatisfactory method. The best mode of clearing away the scum is by a "skimming" apparatus or parachute, which effectually

accomplishes the operation with cleanliness, certainty, and ease.

The apparatus consists of a tinned copper basin with a valve in the centre, and a tinned brass tube which works in a stuffing box fixed in the bottom of the tun. The whole of the apparatus is raised or lowered by means of a rack and pinion, or a screw worked by a hand wheel at the front of the tun.

The edge of the basin is thus so set that it is very slightly above the level of the beer. As the yeast forms it falls over into the copper basin, and is let off at pleasure by pulling a cord attached to the valve, it then passes down the brass tube to a yeast trough below.

The number of fermenting tuns required must be regulated by the frequency of brewing. Where skimming is not adopted the beer remains in the fermenting tun three days, but if skimming is practised, about six. The position of the fermenting tuns must be such that the beer will run into them from the refrigerator, and they must be high enough from the ground to give height underneath for cleansing casks.

Each tun should be provided with a discharge cock with hose union, through which the beer is run off to the cleansing casks; a wash-out cock with connection to an open head, communicating with a trapped and ventilated drain; a copper funnel, also discharging into the same head, for taking the overflow from the attemperators, which overflow must be in sight, so that the brewer may regulate the supply of water. There should also be hot and cold water laid on to each tun for washing purposes, and a removable cover and yeast boards which may be regulated as the fermentations require air or otherwise.

The double fermenting square used in Yorkshire, to which allusion has been made, consists of an inner close square with an exit pipe from the cover through which the yeast escapes. In this the worts are innoculated with the ferment, and the space between its walls and those of the exterior square is filled with cold water, the interior is also fitted with an attemperator. Then, by passing cold water through the latter and the exterior chamber, the heat is kept down to about 56° Fahr., at which temperature the cleansing is conducted.

Cleansing.—After the fermentation in the tun has flagged, and the chief portion of the yeast has been removed by skimming or otherwise, particles of yeast and glutinous matter still remain held in mechanical suspension. Could these be even removed by filtration the liquid would still appear muddy, since the fermentation has not completely ceased, and as long

as this lasts fresh particles of yeast will be generated, and these will keep the beer turbid and impure. Further, when vinous fermentation takes place in a liquor, it is always succeeded, if left to itself, by the acetous fermentation. This further fermentation is prevented by the cleansing process.

Cleansing is effected in a variety of ways, the oldest method, which is still extensively practised, is to run the beer from the fermenting tun by means of a hose into ordinary casks laid side by side on a trough or stillion about 2 feet high. The beer remains in these casks for several days, the bung hole being left open, and through it what little yeast is left in the beer works out and falls into the stillion beneath, when the discharge ceases the beer is ready to be bunged up and put into store.

In the system thus described the cleansing casks have to be kept filled up, or "topped up," as it is termed, by hand labour. To obviate this an automatic arrangement is used in many breweries, which may be thus described. The ale to be cleansed is pumped into a large trough and then run into the cleansing casks, above which it stands, by a movable or sliding tube; when the cask is full the communication is stopped with a wooden plug, leaving a second pipe inserted in the bung hole of the barrel with its mouth turned over the top edge of the trough; this pipe is called the swan-neck pipe. Through this pipe the froth arising from the fermentation forces its way and is transferred to the yeast trough, where the yeast is deposited. To keep the casks full and enable the froth to rise to the yeast back, a quantity of beer is put into the reservoir and thence conducted to the cleansing cask by the sliding tube before mentioned.

After the fermentation has continued in this state for one or two days it apparently subsides; the contents are then allowed to rest for a few days longer, and the clear ale is then drawn off by means of a screw tap which projects into the cask, and by turning this the screwed portion so far projects above the dregs that the beer may be racked off fine to the last.

The principle of union cleansing casks is similar; but the beer is racked off into long troughs, and there is a long supply pipe in place of the sliding tube, the "swan necks" delivering into the yeast back as before described. The casks are mounted on trunnions like a churn for facility of cleansing. The union system is more used at Burton-on-Trent.

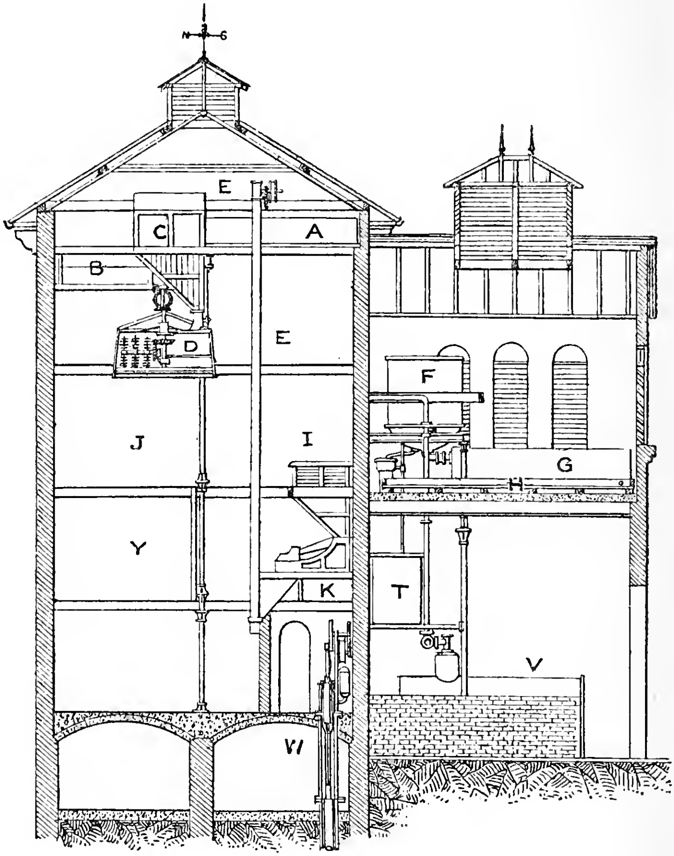
Another system of cleansing, principally used by the large porter brewers, is to use "pontos." These are vessels in shape of vats, holding from four to ten barrels each.

The pontos are placed in a double row with a yeast stillion

between them. The beer is run into the pontos, and the yeast works out through an opening in the head into the stillion. The feed back is a similar vessel, and furnished with a skimming apparatus, the same as that described for fermenting tuns.

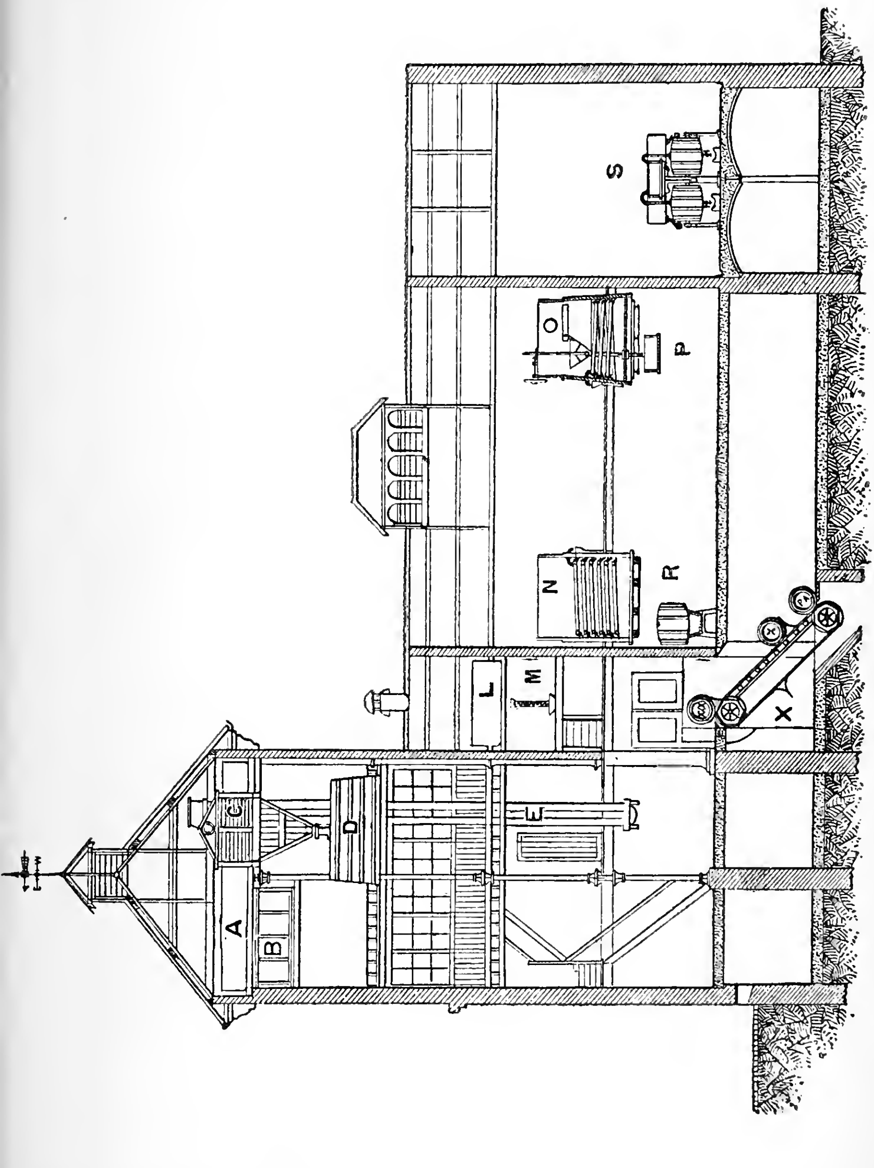
There are several other modifications of the cleansing process, but the principle is the same in all of them. This completes the ordinary process of brewing.

The additional apparatus required is a yeast press, or filter,



In the Diagrams, A is the cold-liquor tank; B, hot-liquor back; C, grist case; D, mash tun; E, elevator and malt screw; F, steam copper; G, hop back; H, cooler; I, malt hopper; J, malt store; K, malt mill; L, attemperator tank; M, refrigerator; N, fermenting square with attemperator; O, fermenting round, with attemperator and skimmer; P, yeast back; R, stillion; S, union cleansing casks; T, condensed-water tank; V, boilers; W, artesian well and pump; X, cask-raising apparatus; Y, hop store.

for taking the beer out of the yeast; a cask lift for bringing barrels out of the cellar, which may be constructed on the principle of the elevator, with endless chains, and a carriage to receive the barrels; and last, but not least, cask washing and steaming apparatus for washing casks; this may be performed in a simple and effective manner by means of a nozzle, to which both steam and hot liquor are conducted; the hot liquor is



first turned into the cask, and then steam put on, by which the cask is effectually washed over its whole surface.

The engines and boilers should be of the most simple construction, strength in all parts being a necessity for brewing work, the boilers are best of the double-flue Lancashire type, and should be in duplicate; an independent steam feed pump, capable of pumping hot water, being also indispensable in breweries where the boiling is performed by steam. There are many other points of minor detail, such as superheated steam, returning the condensed water of the coils to the boilers direct, and such like, to which he could only refer.

The subject is a large one, and a paper might be written upon each of the sections alone; it is a field which affords ample scope to the engineer for labour-saving appliances, and improvements in the arrangement and construction of buildings; while to the chemist it is an ever fresh study, the principles of fermentation alone having engaged the earnest attention of some of the master minds of our day.

In conclusion, he hoped that they would pardon the hasty manner in which he had been forced to treat the many points of detail with which they had to deal in the construction and arrangement of breweries, and that the paper had not been altogether without interest.

The author mentioned that he found the water-meter of Messrs J. Tylor and Sons, 2, Newgate Street, London, as the most suitable for breweries, and that when the brewer took water from a town supply, it would be advisable to have one for his own satisfaction. (A model was shown of this).

Models were shown and explained of a magnetic apparatus for cleansing malt, and of Sorrel's patent rouser for fermenting tuns, both lent by Messrs. Stopes and Co.

Messrs. Lawrence and Co.'s corrugated refrigerator was shown and explained by models and sections. Mr. Maignen's "Filtre Rapide," for filtering brewing water or beer, was illustrated by models of the apparatus.

A very complete and beautiful model of union cleansing casks was lent for the occasion by Mr. E. Pearson, cooper and vatmaker, of the Grove, Southwark, S.E.

DISCUSSION.

The PRESIDENT said that they were told that when they went abroad they ought to do without beer, and drink the wine of the country. He believed that beer was essentially the wine of England, and that its use would never die out in

this country. It was very necessary that it should be as pure, good, and economical as it could be made. From what he had seen in some breweries, he was quite sure that it would be impossible to deal fully with the machinery of breweries in one paper. At the same time Mr. Kinsey's paper was very condensed, and very valuable and useful.

Mr. F. Colyer said he agreed with Mr. Kinsey that enamelling cast-iron plates for cold-liquor backs was a bad plan, and that a better one was to line them with glazed bricks set in Portland cement. He had done this on a large scale, and it was perfectly successful. Enamelling was a failure, whether used for cold-liquor backs or for any of the other vessels in a brewery. With regard to grinding the malt, Mr. Kinsey had recommended two unequal rolls; but that recommendation did not accord with his (Mr. Colyer's) practice. He used rolls of equal diameter, and geared together. Where only one roll is driven, there is a large amount of slip, and much trouble is occasioned. He agreed with Mr. Kinsey as to the power of the rolls; when brewers required to grind more than thirty quarters an hour, it is better to increase the number of the mills than the size of the rolls. In large breweries there are often two or three separate sets of rolls. The rolls were sometimes steel cased, and in some respects there is an advantage in this. They do not require turning so often as cast-iron rolls, but they are very expensive as to first cost. Upon the whole, however, he preferred to use chilled cast iron. As to the mashing machines, Mr. Kinsey had said that they were usually driven from above. He (Mr. Colyer) was sorry to differ on that point. He thought that they were better driven from below the mash tun, and there were several reasons why they should be so driven. One was, that in ordinary sized tuns there would be no gearing of any description on the top, and the cover of the tun could be put close down, so as to leave but little space above the goods, the heat of the mash being thereby retained, and that was a very important matter to the brewer. In some large breweries the covers of the mash tuns were made of copper in the form of a dome, and raised and lowered by machinery. As these covers were of a very expensive character, they could be used only in very large establishments. The cover of a mash tun in an ordinary sized brewery was made of wood. As to the false bottoms, Mr. Kinsey, he thought, had made an error in saying that the holes ought to be one-eighth of an inch in diameter. The holes when they were drilled ought not to be more than from one-sixteenth to one-twelfth of an inch diameter. The piece of false bottom which had been passed round the room

was a sample of Riley's patent plates; he assumed Mr. Kinsey's remarks did not apply to this. With regard to steam coppers and fire coppers, he could not enter into any discussion of their merits as far as the process of brewing was concerned. He could only state that as regarded economy in fuel and convenience in working the advantage was decidedly in favour of steam coppers. At Burton-on-Trent they had a great prejudice against steam coppers, and the question was one which must be left entirely to the brewers, and was generally beyond the province of the engineer to decide which should be used. The jackets were best made of wrought iron, and should be protected with Leroy's or some other patent non-conducting composition. Many brewers now preferred to protect the side of the copper as well with the same material. Mr. Kinsey had said that the hops occasioned some difficulty in the copper. Probably Mr. Kinsey was speaking of a steam copper. He (Mr. Colyer) did not think there was much difficulty about them. A large strainer was put over the bottom of the copper at the outlet. When the copper had to be cleared of the hops, the strainer was raised by gearing from the top. The strainer should be made of drilled or slotted copper plates fixed to a gun-metal pan. Mr. Kinsey had said that wood was the preferably material for the coolers. He (Mr. Colyer) was sorry to differ from him there, for he believed that wood was about the worst material when the engineer was allowed to use any other. He believe that the best material was thin copper plates. It was now eighteen or twenty years since his late friend Mr. T. King, C.E., the engineer of Truman's brewery, put down the first copper coolers. He believed that some gentlemen from Messrs. Truman's were present at the meeting, and they could state that these coolers were at present at work, and in perfect condition. The expense of copper was not excessive. A copper cooler costs only about double the price of a cooler constructed of wood. Wood would cost from 2*s.* 6*d.* to 2*s.* 9*d.* a superficial foot, and copper about 5*s.* 6*d.*, according to the market value of copper. Experience had shown that, as far as engineers had been able to judge, there was no deleterious action at all resulting from cast iron. One would not advise wrought iron, for it would involve the difficulty of rust. He was sorry that Mr. Kinsey had not given them a little more information about refrigerators, for there were many which were equally good in their way, and it might have been interesting to the Members to have learned a little more about them. Perhaps he would say something more about them in his reply. He (Mr. Colyer) could name Baudelot's, Riley's, Morton's, Bindley's, and others, all

good apparatus. Mr. Kinsey had mentioned the use of what were called stone squares for tuns in Yorkshire. Perhaps it would have been as well if he had mentioned that, as a rule, tuns so made were seldom or never used outside Yorkshire, and were peculiar to that county. He (Mr. Colyer) had only met with them in one or two breweries elsewhere. He could not agree with Mr. Kinsey that the depth or size of the fermenting tuns was not a matter of much importance. According to his (Mr. Colyer's) practice, he regarded the size as of great importance, especially with regard to depth. According to his experience, the depth ought never to be more than from 4 feet 6 inches to 5 feet from the bottom to "fill" line. The capacity of the tun was left to the brewer, for very much depended upon the particular system of brewing; and therefore the size of the fermenting tun was not always within the province of the engineer. He agreed that round tuns were much better than square ones, as they were very much more easily cleaned. With regard to the material of which they should be made, fir was generally preferred as a rule, although in many breweries they used oak.

Mr. Doggett congratulated Mr. Kinsey on the able manner in which he had put the matter before the Society. Mr. Kinsey had, however, he thought, gone a little more into the subject of brewing than into the engineering points connected with it. He (Mr. Doggett) agreed with both Mr. Kinsey and Mr. Colyer to a very great extent in their remarks, but, being there as a listener only, had not taken any notes, and consequently did not know that he could say anything more, unless they required a dissertation on brewing, which he thought would be rather out of place.

Mr. Bernays said that he had had no experience whatever in this branch of engineering. There were, however, many parts of Mr. Kinsey's paper which were worth discussion. For instance, the getting of water for brewing was a most interesting and important subject. One point which he had mentioned, and which he (Mr. Bernays) had not heard mentioned before, was that he had used concrete tubes 4 ft. in diameter for lining a well. He should like to know something about these concrete tubes. What was their thickness and height and length, and how were they put together so that they might be made sound, and might work properly. He had had a little to do with the boring for water, but not in connection with breweries. In one part of the paper Mr. Kinsey said that sometimes there were two or three waters in a well, and it was difficult to separate them, and that the brewer wanted two sorts of water for different

beers. It would be interesting to know how to separate the two waters in the same well at different heights. No doubt it could be done, but he had never heard the process described. Perhaps Mr. Kinsey could give some information on the subject. Then the author had said something about different classes of fermentation in connection with English beer and German beer; the former being produced by rapid fermentation, the latter by slow fermentation. Mr. Kinsey would perhaps be able to say whether this difference in the method used for fermentation was the cause of German beer generally being less hot in the mouth than the beer brewed in England.

Mr. LUCK said that he should like to have heard Mr. Kinsey speak of the machinery connected with the process of using raw grain. That was a very important point in connection with brewing at the present time, in consequence of the abolition of the malt tax. He had also spoken of the use of gypsum in water for brewing. That was a very important point; for not only did the gypsum do what Mr. Kinsey had stated, but it also had the power of decomposing gluten even after the wort had finished fermenting. He should have liked to hear a statement from Mr. Kinsey in connection with the point at which the engineer came into co-operation with the chemist, by treating the mechanical part of the brewery in such a way as to assist the chemical processes.

Mr. H. STOPES said that he felt very much indebted personally to Mr. Kinsey for the very able paper which he had read. The paper contained a few statements which called for a little discussion. He was surprised, at the outset, that so little had been said in connection with the great change which all brewery construction must undergo in consequence of recent legislation. Some of the breweries which had been recently built were very great improvements upon those which were built even twenty years ago; but there was no doubt whatever that in the future very much greater improvement would have to be made. Many new things were being introduced into breweries which would necessitate new machinery and new modes of working, which would altogether revolutionise the trade. There was no doubt in his mind that we should speedily have lager beer freely brewed and consumed in this country, and there would be lager breweries, upon systems altogether different from those which were now in existence in our midst. There was another very wide and important subject about which he had expected to hear a good deal, and that was the use of raw grain. There was no doubt whatever that we should have raw grain very largely used, both in our ordinary breweries and also in the

lager beer breweries which would, in all probability, be erected in the next ten years. These were subjects which might have been treated in an engineering paper on breweries, and he was sure that they would have all felt very great benefit in hearing them treated in the very able manner in which Mr. Kinsey would have treated them. Turning to the paper, he should like to know what limestone was used in the fen countries. Mr. Kinsey had spoken of gypsum being used, and also of water passing through limestone. He should like to know the object and the benefit of that mode of procedure. As to grinding, his own experience failed to confirm one or two of the things which had been said by Mr. Kinsey. In the first place, he did not think that they ground properly in this country. Malt which was simply crushed between smooth rollers was not ground in the best method. The process produced a large amount of flour, and it did not properly separate the husk from the interior kernel, and it did not granulate to a sufficient degree of fineness. Then he thought that it was a fallacy for a brewer to put up a mill which was capable of doing the whole of his work in an hour. It was said that it was advisable to have mills which were capable of grinding as much as the whole of the grist in an hour. He thought that this was an error. It was a waste of power, and it had several other disadvantages. He did not think that sufficient importance was attached to the mashing process. They had heard a great deal about fermentation being the most important process, but he begged leave to differ from that statement. He maintained that fermentation was a very unimportant process compared with the mashing, because by the mashing they could regulate the fermentation. If they had wort which was not capable of being properly fermented, they could not ferment it, no matter how much care was taken. Then he did not think that sufficient importance was attached to the proper use of under backs. The under back, as generally used, was an objectionable appliance; but if it was used as a supplementary copper it was a very great saving to the brewer, who had a very great amount of starch in his wort. The evil of working wooden boiling backs with false bottoms was undoubtedly a great one, and he quite agreed with Mr. Kinsey in this respect. It was a wrong thing, in his opinion, to boil wort in a wooden vessel at all, and it certainly had very great disadvantages to attempt to boil it with a heavy false bottom which did not allow the wort to circulate freely in it. He thought that the steam-jacketed copper was a very useful vessel. Those who had used steam coppers very much disliked fire coppers; at least, he had found it so. He thought

however, that three barrels per quarter as the contents of the copper did not allow sufficient play. He did not think that the brewer had sufficient room if he only had three barrels per quarter in his copper, and he would not then have the power of making up in a single charge if he wished to do so; and this was sometimes of very great use. He also thought that the hop backs were totally unnecessary. He believed that they were really a disadvantage in a brewery. With regard to the depth of the fermenting tuns, he quite agreed with the remarks that Mr. Colyer had made. It was a most important thing not to have the wort too deep. That was a point which fairly came within the functions of the brewery engineer. He thought that in the remarks with regard to the galvanic action and the use of a portable attemperator, the paper did not bring out the fact that they might get galvanic action in fixed attemperators much more readily than in portable ones.

Mr. ~~Godfrey~~ (Messrs. J. and E. Hall) said that he was connected with a cold dry air refrigerator, which he thought would be very useful in breweries, and that this system of refrigeration was being used by one of the chief breweries in London. The refrigeration was carried on by means of cold air, which was delivered from the machine at a temperature of about 40° or 50° below zero. He thought that this refrigerator would be very effective in the way of attemperating, cooling of worts, &c. It was very easy to handle, the machine being very simple, and worked by cold air only. There being no acids, or ether, or ammonia (which were in themselves either inflammable or corrosive, hence dangerous), it was not likely to get out of order, or to require much skilled attention. The *modus operandi* is as follows:—Air is compressed in a water-jacketed double-acting cylinder, where, as a natural consequence, it gets heated; it is then passed through a series of coolers or surface condensers, when, by the aid of circulating water, it gets cooled down to within 5° of the initial temperature of the water; from these, and still under pressure, it passes to another cylinder, where it is expanded and made to do work, thereby reducing its temperature to 50° or more below 0° F.

Mr. Lawrence said that he had a patent refrigerator which was used for passing cold air, and at the same time for sparging water from the top, so that they had not to use a large quantity of water.

Mr. Young, referring to the remark of Mr. Colyer, that rollers of unequal size were not advisable, said, that it was the practice of Messrs. Pontifex and Sons, the firm with which he was connected, to make the rollers unequal in their diameter

in the proportion of one to two. They found that there was a great benefit derived from the inequality. The large roller was driven, and the small one revolved by friction of the malt passing through the rolls. The consequence was that there was no gearing required, and the rollers always worked more freely and ran much lighter. They made much less noise than if they were geared. There had been a question in connection with the mashing machines, as to whether they should be underdriven or overdriven; Messrs. Pontifex drove them from above whenever it was practicable. The reason was, by so doing they avoided leakage from the stuffing-box, which soon got worn and became a source of trouble to keep tight. There was likewise considerably less strain on the bottom of the tun, which, if of wood, was a great consideration. It had been mentioned that underdriven machines had the advantage of using close covers on the tun. The same covers were used for overdriven machines, as the driving wheels were quite out of the way. In either case, the covers invariably had a hole in the centre for the sparger to revolve. Most brewers, however, preferred having a cover permanently fixed about 2 feet 6 inches above the top of the tun, with sliding shutters, or curtains, round the slides, which enabled them to see the mash, &c., without lifting the cover at all, thereby keeping in the heat of the mash. Where a little extra expense was not an object, copper dome covers, as already mentioned, were decidedly the best, and the cleanest for the work. He agreed with most of the remarks of Mr. Kinsey. Respecting the size of the holes in the false bottoms, it was the practice of Messrs. Pontifex to drill them about the tenth of an inch in diameter, and very close to ensure good drainage.

Mr. A. Le Grand said that, although he was not connected with brewing, he had had something to do with obtaining what he should consider a first necessary of a brewery, and that was pure water. He was sure from what they had heard from Mr. Kinsey, that it really would have been impossible for him to deal more fully with the hundred and one different things connected with a brewery within the limits of such a paper; but he had devoted a considerable portion of what he had to tell them to the all-important question of water supply. At the various breweries at Burton alone, he (Mr. Le Grand) had made upwards of one hundred wells, and the system which he had adopted had been the tube well, which was more commonly known for shallow depths as the "Abyssinian" well. For Messrs. Allsopp there had been put down upwards of thirty of these wells. They were subject to floods at Burton, and the

ordinary dug wells were open to contamination even where they had been made, as he had understood, with four courses of hard black Staffordshire bricks set in cement. In producing the iron tube well, there was such compression by the driving of the tube into the ground, that the earth was, practically speaking, far more compact where the well was put down than the natural soil was before it was disturbed by the displacement. He might remark it was very important that the possibilities of the water supply should be ascertained beforehand. He had often met with cases in which a brewery had actually been erected and the water supply never thought of. Perhaps they had obtained the water for building from a company, or by means of a little shallow well, and when they came to brew they found that the water was either too costly, bad in quality, or deficient in quantity. In more than fifty per cent. of the old breweries a great deal of the trouble that was taking place in producing beer and in the fermentation was owing to the quality of the water. Brewers did not like to say much on the subject, but they had to combat against a manifest difficulty from that cause. He wished to draw attention to the fact that the ordinary plan of sinking dug wells was, as a rule, a source of both trouble and great expense in their first cost, and then mischief thereafter. The difficulty was to keep the surface water out. Even when wells had been dug in order to get the water from artesian sources, the top water would get in. It was advisable, when possible, to dispense altogether with the sinking of a shaft, except a dry shallow one, for the purpose of placing the pumps below the surface.

Mr. Arthur Rigg said that everybody who looked at the drawings on the walls, and heard Mr. Kinsey's paper, must notice that an enormous advance must have taken place within the last few years in the machinery and appliances for brewing. Scientific refrigerating had almost been invented, while a knowledge of the influence of bacteria upon fermentation and putrefaction seemed almost to have given a new starting point to improve the purity of beer. Although such subjects as these are not directly connected with engineering, yet they were most properly brought forward on this occasion, for all sciences are becoming more and more closely related to each other. It has been said that injury resulted to the beer if pumped during the process of manufacturing, and that was the reason why such lofty breweries are now used all through the country. The plan of supplying the water from the top of the building, and letting each process command its successor, was an obvious advantage in simplicity and directness; but why

pumping should do harm to the brewing he could not fully understand. It almost seemed as if the only reason why pumping could damage the liquor was by the extraordinary disturbance which most descriptions of pumps caused to the water during the process of pumping. It was well known that such disturbance wasted a very considerable amount of power, but so long as the water was clear, no other harm could result from the agitation. But pumps are made in which the water was simply lifted, and not, as it were, churned during the process, and he should be interested to know whether any such pumps had ever been used in breweries, and if so, whether their effect upon the beer was injurious or not? There was another matter which he had oftened noticed in breweries, and there must be some very good reason for it, and that was the general employment of non-condensing instead of condensing engines; because, if the water that had to be used were passed through surface condensers, it would extract heat, and there would undoubtedly be fuel saved. So much is now done in a scientific direction in improving breweries, that it seemed natural to ask why brewers did not appear to pay any attention to a matter like this, involving waste of fuel. If some practical brewer would enlighten them on the reasons of the one or two things which he had spoken of, it would be an advantage; for unless the engineer learns what are the wants he has to meet, it is impossible for him to provide the machinery and appliances essential for the scientific production of beer or anything else.

Mr. Maignen said that he did not know much about breweries, but he had learned in practice in the wine trade that liquids which were to be drunk were much better to the eye and to the taste for being bright than when they contained impurities. During the last three years particularly, he had paid considerable attention to the clarification of liquids, and during the last two years 2000 filters of the description of the one shown upon the table had come into use for clarifying wines and spirits of every description. Experts in brewing had suggested that these filters might be adopted in breweries for several purposes. In the first place, there was the question of the clarification or purification of the water. Mr. Kinsey had well described the process of the filtration or clarification of water from organic impurities. The asbestos cloth, which was not liable to decay, made a very good matrix for the filtering medium to settle upon. The filtration must be slow in order to be effective, and if it was to be done rapidly, a large filtering surface must be presented to the liquid. The impurities left in a filter ought to be got rid of as soon as possible. Hence

self-cleansing filters of small area must be, as Dr. Macadam had said, a delusion and a snare for the object for which they were intended. He had lately taken out a patent for a charcoal which softened the water. If it were desired to harden the water, it could be passed through gypsum and then freed from mechanical matter by the application of a filter. In some Austrian breweries the filtration of wort was found to be a great success, and he therefore thought that the filtering of wort might be applied in this country also. A number of breweries were experimenting on it now. In the further processes of treating beer, this filter could be depended upon to arrest suspended matter. The filter was intended for light liquids. It would be no use to put solid yeast into it. Cloudy beer should be rendered brighter by means of the filter, instead of by fining by means of isinglass. It was only a question of the multiplication of the filtering surface. There was a larger size in the room made with two frames. One of these filters that was at a recent exhibition, measured 9 feet by 4 feet by 3 feet, and contained 500 square feet of filtering surface. This would be applicable to the wants of a brewery.

Mr. Kinsey, in reply, said that the subject was such a large one, that it was very difficult to deal with it in the condensed form in which it must be treated in a paper of this description. As to the size of the holes in the false bottom of the mash tun, he ought to have stated that they were one-sixteenth of an inch in diameter. He had said one-eighth by mistake. He had had no experience of the lining of the cold-liquor back with enamelled bricks. Mr. Colyer was, no doubt, perfectly right as to the rolls, but his (Mr. Kinsey's) experience was the same as that of Mr. Young, of Messrs. Pontifex's. He had always found the unequal rolls to be very satisfactory when they had not been steel faced or too hard. When they had been too hard, he had found the slip which Mr. Colyer mentioned. In that case, gearing would seem to be advisable. He liked to tear the grain rather than grind it, although Mr. Stokes thought the grinding advisable; but that was a matter in which the brewer must have a voice. The sample of plate which he had exhibited was Riley's patent; he merely showed it as an illustration, and not to advocate it or otherwise. Mr. Colyer raised a difficulty about coils; what he (Mr. Kinsey) meant was, that coils in wooden backs were often a nuisance, because the hops collected round the coils. That was got over by means of a strainer, though many brewers preferred to have no strainer. As to the material for the coolers, he had stated in his paper that he preferred copper, but some brewers would object to

copper on account of the expense. With regard to the refrigerators, he had endeavoured to explain Morton's refrigerator as well as he could in the paper. As to the Yorkshire squares, he mentioned that in Yorkshire they used a particular description of stone squares, and he believed that these were peculiar to that county. Mr. Beckwith had been good enough to say that he should have liked to hear more on the subject of brewing. He (the speaker) would have been glad to say more if the limits of a paper would have allowed him to do so. As to cold air passing through a refrigerator, undoubtedly Mr. Lawrence did claim that in his patent; he (Mr. Kinsey) had had no experience of its use, but he did not see why cold air should not be an important adjunct to a brewery. The tube wells mentioned by Mr. Le Grand were exceedingly useful in a place where there was a good deal of surface contamination, but there would be a difficulty with the tube well if the water would not rise to a pumping distance; that was why he advocated the ordinary artesian well with a pump put down it. This method combined the advantages of the tube-well and the ordinary well, the pump being put down to the depth necessary for raising the water. With regard to the use of gravitation instead of pumping, he did not think that it involved any question of harming the wort by pumping it. A brewery on a large scale could not be entirely a gravitation brewery, for the buildings would have to be of such enormous height. Many brewers preferred to have a gravity brewery, and the engineer had to consult with the brewer as to the style of brewery he would have. One speaker had expressed surprise that condensed water was not used; many brewers had an objection to using it for mashing purposes. The condensed water would be to some extent soft, and some brewers would think that some of the valuable constituents of the water would be lost in the softening. With regard to concrete tubes, they seemed preferable to brickwork, especially when such fine tubes could be obtained as those made by Sharp and Co., of Poole; those of 4 feet diameter were amply sufficient for many of the smaller wells in breweries. He had found that a little cement grout passed round the joint would make a very perfect and tight job. There was far more ease in sinking these tubes than there was in sinking an ordinary brick well lining upon a wooden curb. Where the concrete tubes had been used they had been very satisfactory, especially in cases where the surface waters were uncontaminated and soft, while the lower waters were hard. In such cases, the concrete tubes formed the upper wells for the softer waters, while the artesian boring, going down deeper,

with its internal lining and pump, answered the purpose of drawing up the lower water. The concrete tubes were from $2\frac{1}{4}$ to $2\frac{1}{2}$ inches thick. The limestones were such as were procurable in the district; he should prefer the softer to the hard, because they were more easily acted upon by the water. Carboniferous limestones were not so useful for the purpose as the softer ones. Mr. Holmes had said that the hop back was unnecessary. That was a brewer's question. His experience was that a hop back was generally used, and gave satisfaction. With regard to the question of the cooler and of refrigerating direct from the hop back, he had found that to have a secondary vessel between the hop back and the fermenting tun was a very great advantage in collecting the sediment, and it gave the brewer great liberty for fermentation. At one brewery they used to refrigerate direct from the hop back, and they always had a boiling fermentation; whereas they afterwards had a cooler, and that was stopped.

Mr. Church asked whether the concrete tubes would keep out the surface water; and whether the pressure in the wells would cause the water to be forced through.

Mr. Kinsey replied that they were perfectly water-tight, just as a sewer pipe was. They had answered at the shallow depth to which he had taken them.

The President said that they had had a very interesting discussion. As regards the well that Mr. Le Grand spoke of, he thought that they could not go down to the depth of 200 or 300 feet.

Mr. Le Grand said that they were made 600 feet.

The President, alluding to the question of surface water, said that the water companies were not regardless of the consequences of getting surface water into their wells. Therefore, any brewer who took well water from a water company, might consider that it was as pure as if he had obtained it for himself. As a rule water companies were very particular. He thanked Mr. Kinsey for having caused such an interesting discussion.

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